Lockatong and Wickecheoke Creek Watershed Sediment and Phosphorus Source Report

Dredging of Delaware & Raritan Canal at Wickecheoke Creek Outlet on November 3, 1999

USDA Natural Resources Conservation Service for the New Jersey Water Supply Authority Clinton, New Jersey

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(As Amended)

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Table of Contents

Figures

Tables

Table 14 – Bridge Crossings, Steep Slopes and Streams Crossed 42

Executive Summary

Request and Problem Identification

In 2005 a Memorandum of Agreement was signed, at the request of the New Jersey Water Supply Authority (NJWSA), for the Natural Resources Conservation Service (NRCS) to conduct a study to determine, in part, the sources and amounts of sediment entering the streams and being deposited into the Canal. The study was to focus on the Wickecheoke (17,015 acres) and Lockatong Creek (17,810 acres) Watersheds which represent nearly 65 percent of the total drainage area (in New Jersey) of 53,860 acres to the D&R Canal. This study did not include the drainage from the Delaware River.

The identified problem is the continued sedimentation of the D&R Canal which results in annual public and private costs of nearly $3 million. The Canal serves as the water supply conduit to over 1.5 million Central New Jersey residents. It is also the recreational centerpiece of a 63 mile long linear state park.

Analysis

The two watersheds were subdivided into a total of six HUC-14 subwatersheds. NRCS identified over 1,500 crop fields in the Lockatong and Wickecheoke Creek watersheds. A random sample of twenty percent of these 1,500 crop fields was taken. The twenty percent sample amounted to 308 fields on which the annual soil losses (soil erosion) was determined using the Revised Universal Soil Loss Equation (RUSLE). RUSLE has factors related to rainfall, soil erodibility, length and percent of slope, cover management and conservation practice. Annual soil loss that exceeds the T value results in the degradation of the soil resource. Only 18 of the 308 fields sampled had this soil loss. Twelve of the 18 fields were located in the Upper Lockatong Creek subwatershed. Crops grown in these fields were primarily soybeans and mixed vegetables. Most of the remainder of the crop fields were in permanent hay resulting in very low soil losses on a per acre basis. A gross projected soil loss of 11,978 tons per year results when the average subwatershed erosion rates are projected for all the cropland.

The forest land use category accounts for about thirty one percent of the area of the Lockatong and Wickecheoke watersheds. These forests are mostly smaller woodlots but a few larger forested patches are present in some large forested wetlands throughout the watersheds and on very steep slopes in the southern reaches of the watersheds. Commercial woodland harvests are very limited in this watershed (Shuart, 2006). Forestry activity in the watershed is normally limited to timber stand improvement, some pre-commercial thinning and small scale timber harvests. Timber harvest activities are also severely limited in wetlands by the NJ Freshwater Wetlands Act and along streams by the Flood Hazard Area Control Act (“Stream Encroachment”). Shuart reports that he knows of no erosion problems in woodlands in the watershed and feels that the limited forest activity should not cause excess sediment sources from woodlands. The NJ State Forest Service does not maintain data on timber harvests.

The 10,763 acres of forestland in the watershed has an estimated erosion rate of 0.1 ton per acre per year which results in 1,076 tons of soil erosion from forestland in the watershed. A sediment delivery ratio of 33 percent yields 355 tons of sediment to the D&R Canal.

Field observations indicate that streambank erosion, which occurs throughout the watershed, is a contributing source of sediment to the Canal. Streambank erosion not only serves as a source of sediment but is also a significant threat to the integrity of several county and municipal roads. Episodic events such as Hurricane Floyd and other intense precipitation events may be putting large loads of sediment and rubble into the streambeds which in turn move downstream incrementally, similar to a conveyor belt, into the Canal. Depending on the methodology used, there is an estimated range of 248 to 12,295 tons of soil loss per year due to streambank erosion.

An analysis, using GIS technology, of the stream drainage density vs. the effective drainage density (includes the road network) shows that the drainage density of the watersheds and their subwatersheds is increased significantly by the road network. Field observations of both paved and unpaved roadways in these watersheds indicate that there can be a disproportionate (in terms of the land area affected) amount of sediment moving from both the road network and/or its drainage system and unprotected (from erosion) outlets.
Also, where road stream crossings occur, on both paved and unpaved roads, there is uncontrolled road runoff entering the stream without any sort of pre-treatment. Frequently there is little, if any, area for the installation of a detention basin, check dams or other structural measures due to the steep slopes and relatively narrow stream corridors. A total of 3,723 tons per year of soil loss is estimated to occur from paved and unpaved road surfaces exclusive of any road treatment (such as sand, etc.) used for deicing and winter traction.

Construction sites in the watershed represent a very small portion of the overall land use. There is minimal sediment delivery from construction sites of these sizes due to the relative lack of connection to the existing natural drainage network. Construction activities within this watershed do not have a significant impact on sediment production to the D&R Canal.

Results

Sediment yield (reaching the D&R Canal) is estimated to be coming from the following sources: cropland, forestland, roadways and associated drainage, and stream banks.

Recommendations (in Priority Order)

1. Improve water infiltration into the soil on all land uses.

2. Install measures to reduce the volume and velocity of road runoff to stream corridors from roadways for runoff that is currently disposed of through road ditches/culverts over steep slopes into streams. Measures may include the establishment of stormwater retention areas on private property (with easements) for the infiltration of water back into the soil.

3. Improve water infiltration into the soil on existing hay land, cropland and pastureland by various measures including avoiding agricultural field operations that increase soil compaction, increasing soil organic matter, and others.

4. Acquire conservation easements from property owners and require implementation of forest management plans that have the primary objective of clean and abundant water. Measures may include increasing soil organic matter, micro-topography restoration for surface water storage and better deer management to protect understory and groundcover for reduced phosphorus and nitrogen runoff.

5. Require the development and implementation of a soil and water conservation plan for resource management systems for all farmland assessed property in the watershed.

6. Require a conservation lease on all rented agricultural land that is at least five years in length and renewable at least a year in advance of termination and provide compensation on a pro-rated basis including conservation practices and soil amendments.

7. Develop and implement an on-going information, technical assistance and cost sharing program for all property owners in the watersheds to implement best management practices.

8. Install permanent buffer strips on the approximately 32 percent of the cropland with a distance of 100 feet or less between the cropland and stream corridors using such programs as the Conservation Reserve Enhancement Program (CREP).

9. Retrofit existing gradient diversion and terrace systems where these are causing severe gully erosion at their outlets particularly where cropping and tillage practices obviate their need. Stabilize eroded former surface water runoff outlets. Any new diversion or terrace systems must try to maximize storage and outlets should be to stable outlets where they will

not result in new erosion.

10. Modify stream corridor to reduce the “conveyor belt” movement of sediment, cobbles and other rubble downstream toward the D&R Canal. The “conveyor belt” refers to the fact that material moves downstream incrementally and is highly dependent on the volume of streamflow.

11. This study has been heavily dependent on modeling to develop estimates of the sources of sediment to the D&R Canal. It is recommended that a “fingerprinting” study using radioisotopes be made to more accurately determine the sources of sediment.

12. Exclude all livestock from stream corridors leaving a buffer area to intercept any animal waste runoff toward the stream.

13. Implement pasture management practices to minimize accumulation and runoff of animal waste.

14. Exclude all clean water from stockpiled animal waste and dispose of animal waste by recycling in the soil on cultivated land.

15. Minimize footprint and disturbed area of house and preserve all other topography and vegetation of the site.

16. Minimize driveway length and nature of treatment (unpaved better than paved).

17. Practice regular septic system maintenance with pumping done at a minimum of once every three years.

Introduction

The NJ Water Supply Authority requested USDA Natural Resources Conservation Service (NRCS) to conduct a study to determine, in part, the sources and amounts of sediment entering the streams and being deposited into the Canal.

Literature Review

There has been considerable research on identifying sources of sediment in watersheds.

A study in the Stony Brook Basin in New Jersey found that the average annual rate of suspended sediment discharge was 8,800 tons, or 200 tons per square mile. Annual yields within the Basin, which is in the Piedmont Lowlands section of the Piedmont physiographic province in west-central New Jersey, range from 25 to 400 tons per square mile. A trend analysis of sediment records was performed between 1956 and 1970. It showed that there was an increase between 1956 and 1961. After 1967, sediment yields decreased. This decrease was noted to be due to an estimated 20 percent reduction in sediment discharge from the Basin. This was the result of the combined effect of operation of seven (7) sediment retention reservoirs constructed under Public Law 566 through the then-Soil Conservation Service to reduce sedimentation to Carnegie Lake (Mansue and Anderson, 1974). A report by Drexel University (Phillips and Weggel, 1994) showed that one of these seven reservoirs known as Curlis Lake, had had its capacity reduced to approximately 73 percent of its original capacity due to sedimentation.

A 5-year study (Gellis and Landwehr, 2006) to examine sources of sediment to the Chesapeake Bay began in 2001. Three subbasins were selected for sediment-source studies between 2001 and 2004: the Pocomoke River subbasin in, Maryland and Delaware (157 km^2), the Little Conestoga Creek subbasin in Pennsylvania (110 km^2), and Mattawoman Creek, subbasin in Maryland (144 km^2).

The Pocomoke River subbasin in Maryland was the first analyzed to test multiple fingerprinting techniques for identifying sediment sources in the watersheds. Fingerprints include: ^{7}Be, ^{137}Cs, ^{210} Pb, total carbon, total nitrogen, total phosphorus, and stable isotopes (N and C). The subbasin sampling strategy was focused to distinguish upland sediment sources (land use) versus origin in the stream corridor (stream bed and banks). Potential sediment sources in the watershed were cropland, forest, channel and ditch banks, and ditch beds. Samples of fine-grained suspended sediment were obtained during seven storms between July 2001 and November 2002. Channel corridor (channel and ditch banks, and ditch beds) were significant sources averaging 76.5% of the total sediment sources for the seven storms. Cropland was an important source of sediment for two storms with the highest peak flow which occurred in the late summer and fall when harvesting began and vegetative cover was low. Ditch beds, which contributed an average of 46.1% of sediment for the seven storms, were important sources of sediment over a range of peak flows.

The sources of sediment due to agricultural, construction and other activities are relatively well-known. Lesser known are the impacts of roads and their drainage network on watershed sediment yield. One study (Maholland, B, et al, 2005) found that most unimproved (dirt) roads connect directly or indirectly with streams and, therefore, act as extensions of stream networks by effectively increasing watershed drainage density and subsequently sediment loads to streams. Paved roads contribute to sediment yield through their increased runoff which is collected in ditches and directed through culverts all of which can increase erosion, particularly when the road ditches and/or culvert outfalls are directed to steep slopes which often occur adjoining a stream corridor.

Background

The Wickecheoke (17,015 acres or 26.5 sq. mi.) and Lockatong Creek (17,810 acres or 27.8 sq. mi.) watersheds represent nearly 65 percent of the total drainage area (in New Jersey) of 53,860 acres to the D&R Canal (Figure 1). This study did not include the drainage from the Delaware River. The Canal system is operated and maintained by the NJ Water Supply Authority, a major water purveyor in the state. Approximately 85 million gallons per day (mgd) of water is removed from the D&R Canal (and the interconnected Spruce Run and Round Valley Reservoirs) by five water purveyors (East Brunswick Water Utility, Middlesex Water Company, New Brunswick Water Utility, New Jersey American Water Company and North Brunswick Water Utility) for public consumption by 1.5 million people. Water from the D&R Canal is sold to these water purveyors in a raw, untreated condition. These companies treat the water prior to distributing it to their customers.

Subwatershed names, drainage areas and hydrologic unit codes are shown in Table 1. The location of the subwatersheds is shown in Figure 2.

Table 1 – Subwatershed Names and Hydrologic Unit Codes

Subwatershed Name	Drainage Areas (Acres)	14-Digit Hydrologic Unit Code
Upper Lockatong Creek	5,424	02040105200010
Middle Lockatong Creek	6,173	02040105200020
Lower Lockatong Creek	6,213	02040105200030
Upper Wickecheoke Creek	6,073	02040105200040
Middle Wickecheoke Creek	3,636	02040105200050
Lower Wickecheoke Creek	7,306	02040105200060
TOTAL	34,825	02040105200

Source: NJDEP Hydrologic Unit Code – 14 (HUC-14) Data

Figure 1 - Watershed Location Map

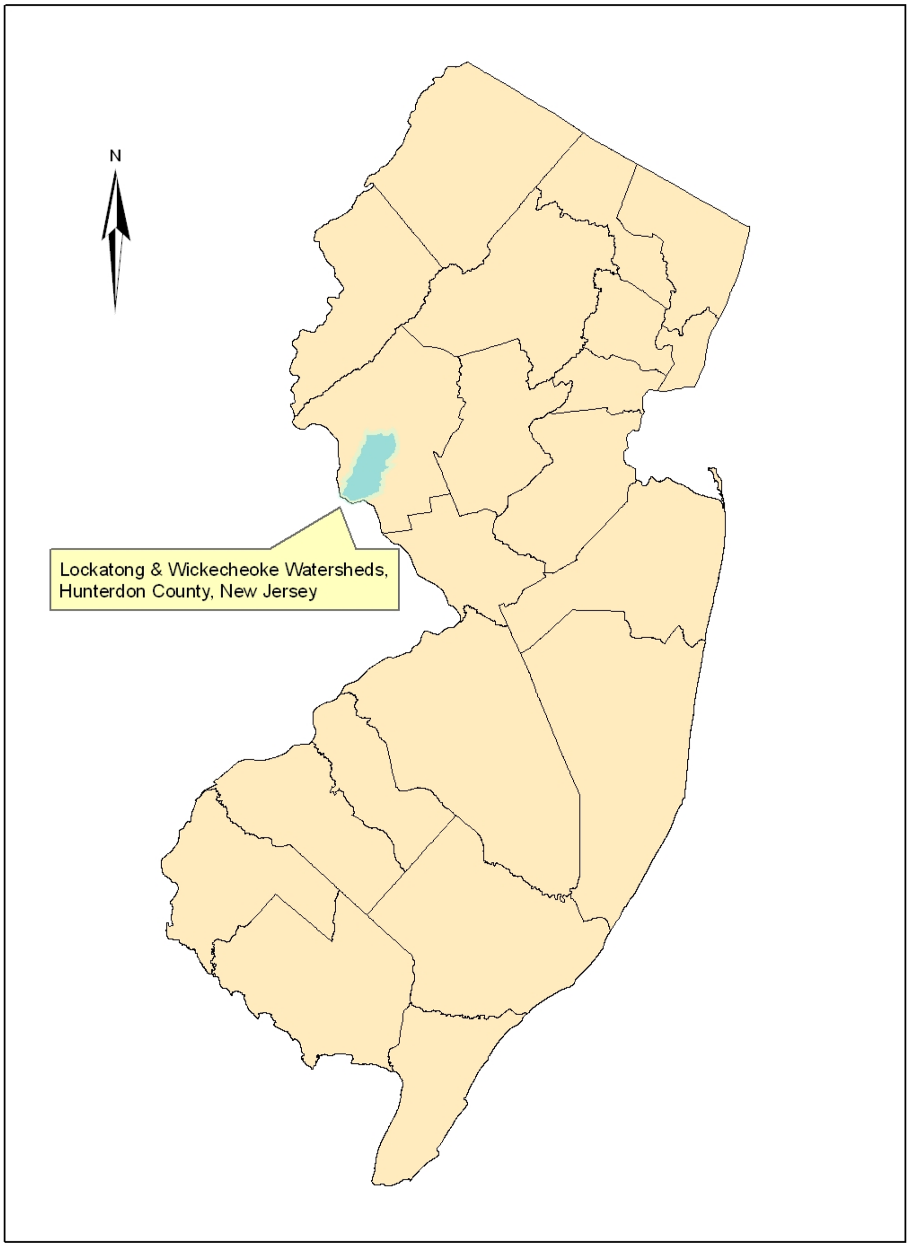
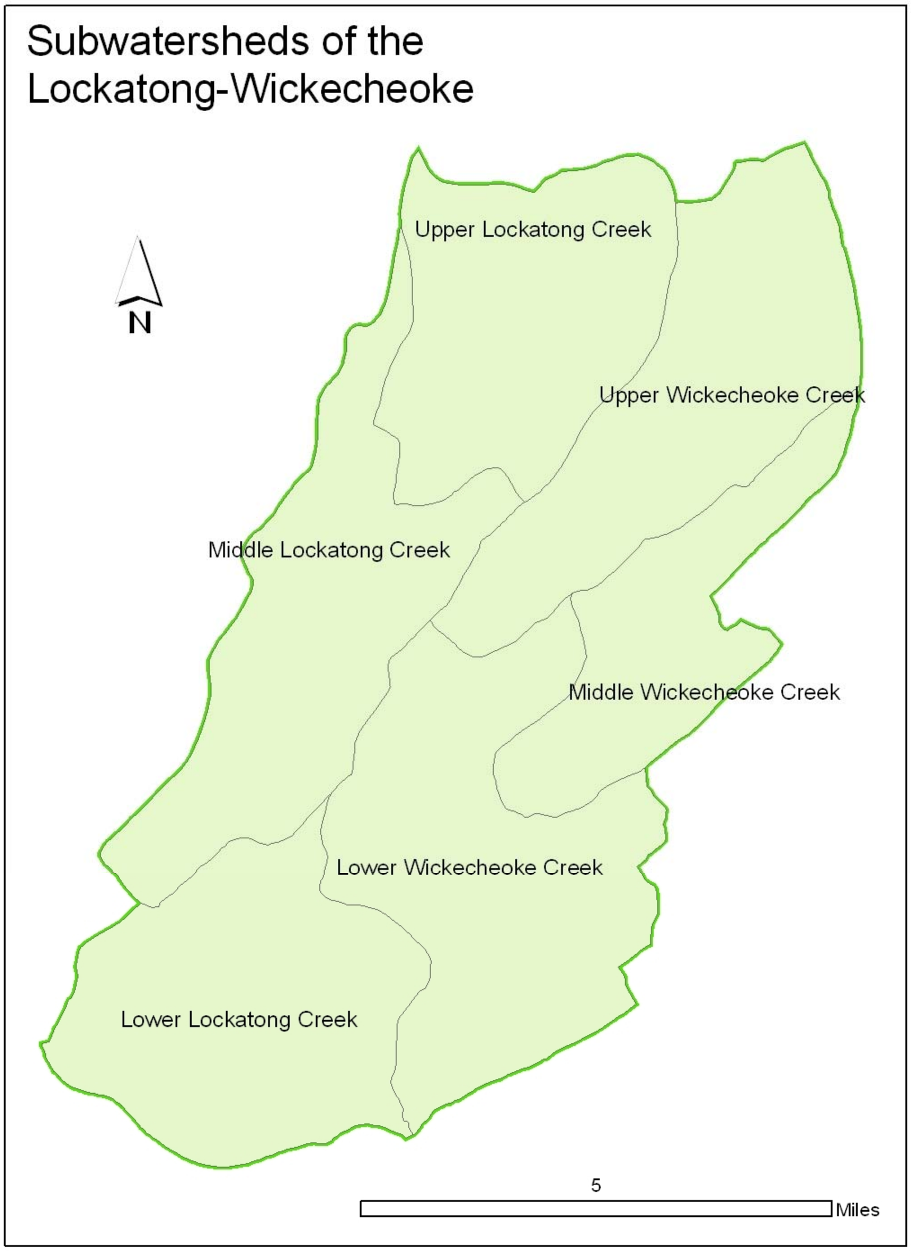


Figure 2 – Sub-watershed Map



Acreages used for cropland and total subwatershed and watersheds in this report vary slightly depending on data source. The Hydrologic Unit Code-14 data layer and NJDEP land cover layer were used for characterizing the watershed in this section. Land use (NJDEP, 1995/97) in the Lockatong and Wickecheoke Creek watersheds is as shown in Table 2.

Farm Service Agency data for cropland was used in the analysis and results for cropland sheet and rill erosion.

Table 2 – Lockatong and Wichecheoke Creek Watershed Land Use

Land Use	Acres	Percent
AGRICULTURE*	13,959	40.1
BARREN LAND	48	0.1
FOREST	10,763	30.9
URBAN	3,450	9.9
WATER	355	1.0
WETLANDS	6,250	18.0
TOTAL	34,825	100.0

* Includes cropland, hayland, pasture, farmstead, etc.
Source: NJDEP 1995/1997 Land Use Cover

Problem Definition

Sediment entering the Canal causes two major problems. First, the larger, heavier particles are deposited in the Canal reducing capacity and thus require frequent removal; secondly the smaller particles remain in suspension and require costly treatment at the water treatment plants. Potential sources of sediment include various land uses including agriculture, new construction, streambank and channels, unpaved roads and unprotected road ditches and outlet and other source.

The soil erodibility is dependent on the soil erodibility factor (K). Other factors that affect soil erosion include the rainfall (R), the length and percent of slope (LS), vegetative cover (C), and conservation practice (P). These factors are further described under the Revised Universal Soil Loss Equation (RUSLE) discussion under Agriculture.

According to the Natural Resources Conservation Service (NRCS) 1986 Sediment, Erosion and Animal Waste (SESAW) Study, the average annual sheet and rill erosion rate from each of the 42,072 acres of “all cropland” in the Delaware Tributaries (upper) (Watershed 7) was 9.8 tons per acre per year. The Lockatong and Wickecheoke Creek watershed is included within this region. At that time, the average annual sheet and rill erosion from the 33,730 “cultivated cropland” acres was 12.0 tons per acre per year for the Delaware Tributaries while the Lockatong and Wickecheoke Creeks had an average of 4.07 and 4.25 tons per acre per year.

In order to narrow down the SESAW results to the Lockatong and Wickecheoke Creek Watershed, Ebasco, an environmental consultant and author of a 1987 study done for the New Jersey Water Supply Authority, obtained the NRCS National Resource Inventory Primary Sampling Unit data base from NRCS and determined the erosion rates for a number of randomly selected points within the watershed.

The Lockatong Creek watershed averaged 7.9 tons per acre per year for cropland and the Wickecheoke Creek watershed averaged 8.7 tons per acre per year for cropland (Ebasco, 1987). Table 3 shows the soil erosion estimates (based on the SESAW data) and computed sediment yield. The total amount of erosional debris exported from a drainage basin is its sediment yield. Sediment yield is generally expressed as either a volume or as a weight – i.e., as acre-feet (one-foot depth of material over one acre) or as tons.

Table 4 shows the cropland and hayland acreage trends between 1987 and 2004. Even though there was an increase in the diversity of non-traditional tilled crops such as sod, the total number of acres of tilled crops (corn and soybeans) dropped significantly. At the same time the acreage of land harvested for hay increased significantly. The total acreage of cropland decreased in both the watersheds.

Table 3 – Lockatong and Wickecheoke Creek Watersheds Average Annual Soil Erosion Rates (SESAW Data) and Estimated Sediment Yield

Land Use	Number of Points	Percent of Area	Average Annual Erosion (Tons per Acre Per Year)
Lockatong Creek			
Forest, not grazed, no commercial harvest	26	34.7	0.10
Corn	10	13.3	13.3
Soybeans	9	12.0	10.2
Cropland not harvested	6	8.0	0.30
Improved hayland	5	6.7	0.35
Farmstead	3	4.0	2.7
Wheat	2	2.7	1.6
Rotation, hay-pasture	2	2.7	1.6
Pasture	2	2.6	0.21
Other row crops	1	1.3	6.7
All other lands	9	12.0	2.08
TOTAL	75	100.0	4.07
Watershed Yield = 4.07 tons/acre-year x 23.1 sq.mi. x 640 acres x 0.15 = 9028 tons/year			
Wickecheoke Creek			
Forest, not grazed, no commercial harvest	21	27.3	0.06
Corn	17	22.1	14.68
Soybeans	7	9.1	6.53
Improved Hayland	6	7.8	0.66
Pasture	5	6.5	1.21
Wheat	3	3.9	4.64
Other Cropland not Harvested	3	3.9	0.29
Farmstead	2	2.6	0.17
Native Pasture	1	1.3	0.19
All other land	12	15.5	0.47
TOTAL	77	100.0	4.25
Watershed Yield = 4.25 tons/acre-year x 26.1 sq.mi. x 640 acres x 0.14 = 9933 tons/year			

Source: Ebasco, 1987

Table 4 – Lockatong and Wickecheoke Creek Watershed Cropland and Hayland Trends 1987- 2004 (Acres)

Crop	Lockatong Creek			Wickecheoke Creek		
	1987	2004	Percent Change	1987	2004	Percent Change
Corn	1,966	391	-80.1	3,691	241	-93.5
Soybeans	1,774	1,208	-28.0	1,520	203	-86.6
Wheat/Small Grain	399	278	-30.3	651	580	-10.9
Sod crop	-	337	337.	-	-	-
Other row crops (including vegetables and nursery stock)	192	55	-71.4	-	25	-
Other Cropland not harvested	1,183			651		
Hayland	1,389	2,275	+63.8	1,303	4,132	+217.1
Total Cropland	6,903	6,221	-9.9	7,816	5,181	-33.7

1987 Figures (Ebasco, 1987 and SCS National Resource Inventory, 1987)
2004 Figures (NRCS, Farm Services Agency, 2004)

Sediment Costs

On-going D&R Canal Maintenance

Table 5 shows the estimated annual costs for sediment in the D&R Canal. According to the New Jersey Water Supply Authority, maintenance cleaning occurs at the Prallsville Lock (mouth of Wickecheoke Creek) at least 12 times a year. Approximately 300 cubic yards of debris are removed from this location annually. The cost for this amounts to $200,000 not including disposal.

Dredged spoil is held at U.S. Route 202 Sediment Stockpile Site. The cost of permanent disposal of the dredged spoil ranges from $20 to $80 per cubic yard.

Major D&R Canal Dredging

Removal of approximately 700,000 cubic yards of sediment from 32 miles of the Canal between Prallsville Lock and Kingston Lock was completed in the fall of 1985. The cost of the project was approximately $20,100,000. This major dredging is anticipated to have approximately a 40 year life span with another major dredging to take place in 2020. It has been estimated that, due to disposal costs, this is likely to cost $40,000,000 which is equivalent to an annual cost of $1,205,000. The remainder of the Canal, which has never received a major dredging, may need to be done sooner than the Prallsville Lock to Kingston Lock section.

Sediment Removal Water Treatment Costs

According to the water purveyor customers of New Jersey Water Supply Authority, suspended sediment in the Canal has been a problem for approximately 15 years. Specifically, since 1997, several water purveyors have noticed that the raw water withdrawn from the Canal (at locations many miles downstream of the Lockatong and Wickecheoke Creek watershed outlet) during precipitation events has required increased amounts of chemicals for removal of suspended solids which, in turn, generates increased amounts of sludge or residuals (Gibs, et al., 2001). Formerly increased turbidity would follow a storm event for up to two days, now it can last up to a week (Falco, 2004; Finnegan, 2004; Maloney, 2004)

A total of approximately $1.5 million is spent annually for the treatment and disposal of sediment in the raw water being taken from the D&R Canal (Falco, 2004; Finnegan, 2004; Maloney, 2004).

Episodic Events

The Hurricane Floyd event on September 16-17, 1999 resulted in major expenses for the New Jersey Water Supply Authority in terms sediment and debris removal from the Canal at various points. The major damage area occurred at the outlet of the Wickecheoke Creek into the Canal at Prallsville, New Jersey (Prallsville Lock). Nearly two thirds of the Canal capacity was filled with sediment, rubble and debris. The cost for removal of this material was approximately $70,000. In September 23, 2004 and April 4-5, 2005 the Delaware River had major flooding. The April 4-5, 2005 event caused approximately $3,500 worth of damages (in terms of equipment and labor costs) (Shepherd, 2005). This does not include the cost of hauling to or the cost of dumping the material at the U.S. Route 202 Sediment Stockpile Site. These numbers were annualized and are presented in Table 5.

Table 5 – Estimated Annual Costs of Sediment in D&R Canal

On-going D&R Canal Maintenance	Major D&R Canal Dredging	Episodic Events (Hurricane Floyd)	Sediment Removal Water Treatment Costs	TOTAL COSTS DUE TO SEDIMENT
$200,000	$1,205,000	$735	$1,500,000	$2,905,735

Sources: Figures for On-going Canal Maintenance, Major Canal Dredging and Episodic Events were provided by New Jersey Water Supply Authority.
Sediment Removal Water Treatment Costs were provided by:
New Brunswick Water Utility
Middlesex Water Company
North Brunswick Water Utility

Agriculture

Sheet and Rill Erosion on Cropland

General

NRCS conducted a study to determine the sheet and rill erosion from the approximately 11,400 acres of cropland in the watershed. The next step was to determine and apply the appropriate sediment delivery ratio. As a result, an estimate was made of the annual tons of sediment being deposited into the Canal from cropland sheet and rill erosion at the point where each of these two streams empty into the Canal.

Methodology

The Revised Universal Soil Loss Equation (RUSLE) was used to estimate the annual soil loss from cropland which is measured in tons per acre per year. It needs to be emphasized that RUSLE only measures sheet and rill erosion which is the movement of soil down slope and not necessarily off the field. Also, some cropland may experience ephemeral and gully erosion which was not measured due to the low number of fields/acres that were in annually tilled cropland. Gully erosion, to a limited extent, on land adjoining cropland is present in some situations where surface water practices outlet. This will be discussed later.

Field Identification

The first task involved the determination of the location and extent of cropland fields in the watershed. The Farm Services Agency-USDA, New Jersey provided their digital layer of tracts, fields and field acreages for Hunterdon County. Using Arc View Geographic Information Systems (GIS) and overlaying this layer on 1995-1997 aerial photography illustrated where the cropland fields were located. A comparison was done of this map to the aerial slides taken by FSA of the County in 2004. As a result, additional cropland was added to the inventory as well as the removal of some cropland fields that had been converted to other uses (mostly urban). Each field was assigned an identification number consisting of the FSA assigned tract and field number. Those fields added to the inventory via the aerial slides were identified with a tract number in the 8,000s and a field number and computed acreage. After combining these two data sources, slightly more than 1,500 fields were then entered into the inventory.

Subwatershed

Each of the two watersheds were further divided into 3 subwatersheds (lower, middle, and upper) using the Hydrologic Unit Code-14 watershed delineation. Any field that was partially in two or more subwatersheds was assigned to the subwatershed containing most of its acreage. For those fields straddling watershed boundaries, if the majority of the field was in the study area then the entire field was included. Very few fields were in this situation.

Random field selection

To simplify and accelerate the process it was determined that RUSLE soil loss calculations would be done on a sample of the 1,500 plus fields. As a result, the decision was made to randomly select enough fields to represent 20% of the cropland acreage. Cropland fields in each subwatershed, that represented approximately 20% of the cropland in that subwatershed, were randomly selected using a random number generator. Due to the relocation of some fields into adjacent watersheds as described above, the 20% random acreage figure varied by watershed.

RUSLE Factors – Use and Selection

RUSLE employs the use of 5 factors to compute sheet and rill erosion from cropland. The definitions of these five factors is shown in Table 6 as well as the range found in the watersheds. In the RUSLE formula “A” equals tons of soil loss per acre per year and is the product of RKLSCP. An explanation of the factors is presented below.

1. **R** factor: Erosive rainfall factor obtained from FOTG – constant of 160
2. **K** factor: Soil erodibility factor obtained from FOTG for each soil series, and then adjusted for RUSLE. The K value for the dominant soil in the field was used.
3. **LS** factor: Length and slope factor obtained from field office data gathered in either making Highly Erodible Land determinations or conservation planning. Many LS factors for each soil mapping unit were gathered and then a representative factor selected from the several values. In-field LS factors were calculated only in a few isolated cases where existing field office data was not available.
4. **C** factor: Cover management factor, all 300+ fields were observed in the field (as opposed to viewing aerial photographs, etc) to determine the current cropping pattern. Based on the field observation an appropriate C value was chosen.
5. **P** factor: Practice factor, an appropriate factor was chosen based primarily on the cropping pattern, row direction, buffer strips, or terraces through the visual field inspection described for the C factor above.
6. **T** factor: Not a component of RUSLE, but is the comparison soil loss to which "A" is compared. For a given soil, "A" should be less than or not greater than "T". The "T" value represents the maximum annual soil loss which can be tolerated for the maintenance of soil productivity.

Table 6 - RUSLE Soil Loss Factors in the L&W Watershed (A=RKLSCP)

Soil loss equation (RUSLE) Parameter	Name/function	Variability in range in Watershed
A	Annual soil loss in tons per acre per year	Values found during study 0.04 to 9.98
R	Erosive rainfall index	Constant of 160 (Hunterdon County)
K	Soil erodibility index	Values from 0.17 to 0.35
LS	Length and % slope factor	Computed by soil mapping unit- values range from .26 to 1.86
C	Cover management factor	Values from 0.004 to 0.43
P	Practice factor	Values from 0.7 to 1.0
T	Soil loss tolerance	2 to 5 tons per acre per year

Results

As noted above, all 5 of the RUSLE soil loss factors were gathered for each of the 308 randomly selected fields. The factors were entered into an EXCEL spreadsheet and the soil loss for each field was calculated. The results are presented in the Table 7. Column 9 shows the average soil loss in tons per acre per year for the 20 percent sample of cropland in each subwatershed. The average soil loss was multiplied by the number of total acres of cropland (col.2) to produce the projected annual soil loss (in tons) from all cropland fields in each subwatershed and is shown in column 10.

Discussion

The soil loss numbers discussed here are for a point in time and are based on a 20 percent random sample. Since farmers frequently change cropping patterns or rotations the soil loss figures will change accordingly. A review of Table 7, column 9, above shows that soil loss in the watershed, on average, is well within acceptable limits. "T" values, or acceptable soil loss per acre per year, for the watershed soils range from 2 to 5 tons per acre per year. Most of the cropland fields in the watershed have "T" values of 3 and 4. The primary reason that there are low erosion rates is that most of the cropland in the watershed is being used to produce grass hay. Eighteen (18) of the 308 fields sampled had annual soil losses which exceed the "T" value. Twelve (12) of the eighteen (18) fields were located in the Upper Lockatong Creek subwatershed. Crops grown in these fields were primarily soybeans and mixed vegetables. A gross projected soil loss of 11,978 tons per year results when the average sub watershed erosion rates are projected for all the cropland.

An inspection of the raw data (soil loss for each of the 308 fields sampled) indicates the following:

1. The total soil loss from all 308 fields was determined to be 2, 293 tons per year.
2. The lowest calculated soil loss was 0.04 tons/acre/year (grass hay on a relatively flat field) while the highest was 9.98 (soybeans on an 8-15 percent or C slope)
3. The majority of fields sampled (252 of the 308 fields or 81.8%) had a soil loss of less than 1 ton per acre per year
4. Eighteen (18) of the fields (5.8%) were experiencing soil loss greater than acceptable limits ("T").

Below in Table 8 is presented the annual soil loss for each of the 308 sampled fields. Each field is placed into one of five groups. A careful review shows that over 90% (93.2%) of the fields have a soil loss of less than 3 tons per acre per year. Three fields had annual soil losses greater than 3 tons per acre but less than 4 tons per acre.

Table 7 –Crop Field Soil Loss by Subwatershed

				Acres of cropland types (in 20% sample fields)					
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Sub-Watershed	**Total* Acres ------------ Cropland Acres****	**No of fields smpld.**	**Acs. smpld**	**Grass hay**	**Small grain**	**Vege-tables**	**other**	**20% Sample average soil loss tons/ Ac/Yr**	**Projctd. gross erosion from sub WS in tons per yr.**
Lockatong-Lower	6,184 / **1,260**	35	252	218	16	0	17	0.44	554
Lockatong Middle	6,186 / **2,229**	61	455	232	103	0	83	0.72	1,605
Lockatong Upper	5,420 / **2,732**	56	516	133	272	12	99	2.79	7,622
Wickcheoke. Lower	7,301 / **2,763**	81	551	443	104	0	4	0.57	1,575
Wickcheoke. Middle	3,633 / **580**	27	140	122	0	0	18	0.09	52
Wickcheoke. Upper	6,069 / **1,838**	48	362	308	12	0	28	0.31	570
Totals	34,793 / **11,402**	**308**	**2,276**	**1,456**	**507**	**12**	**249**		**11,978**

* Subwatershed and Watershed Acres are based on HUC-14 data

** Cropland Acres are based on Farm Service Agency Cropland Data

Note: A 20 percent random sample was taken and therefore the averages are not true averages. The true average could be considerably higher or lower.

Table 8 - Annual soil loss by field, subwatershed and amount (308 sampled fields)

	Number of Fields with Annual Soil Loss (tons per acre per year)					
Subwatershed	**0.0 to 0.99 t/ac/yr**	**1.0 to 1.99 t/ac/yr**	**2 .0 to 2.99 t/ac/yr**	**3.0 to 4.99 t/ac/yr**	**5.0 to 10 t/ac/yr**	**Total fields**
Lockatong-lwr	32	1	1	1	0	35
Lockatong-mdl	50	1	7	3	0	61
Lockatong-upr	31	6	8	6	6	56
Wickecheokee-lwr	67	6	4	2	1	81
Wickecheokee-mdl	27	0	0	0	0	27
Wickecheokee-upr	45	0	1	1	1	48
Total	252	14	21	13	8	308

Table 9 - Lockatong and Wickecheoke Creek Watershed Cropland Sediment Yield

Watershed	Projected Gross Erosion from Cropland* (Tons/Year) Source: Kent Hardmeyer	Sediment Delivery Ratios Source:Max Olynyk	Sediment Yield to the Canal Tons/Year	Cubic Yards/Year**
Lockatong Lower -	554	25 %	139	103
Lockatong Middle -	1,605	23%	369	273
Lockatong Upper -	7,622	20%	1,524	1,129
Wickecheoke Lower -	1,575	20%	315	233
Wickecheoke Middle -	52	30%	16	12
Wikecheoke Upper -	570	23%	131	97
TOTAL	**11,978**	**-**	**2,494**	**1,847**

* This is based on the average soil loss rate for the 20 percent sample of cropland (Table 7, Column 10). Includes sheet and rill erosion.

** Assumes 1.35 tons per cubic yard or 100 lbs/cu foot (Max Olynyk, 2005)

Table 9 shows the sediment yield to the D&R Canal due to cropland erosion. Sediment is removed from the Prallsville (Wickecheoke Creek) Lock on the D&R Canal at least 12 times a year. Approximately 300 cubic yards of debris (wood and household trash) is removed from this location annually (Joe Shepherd, NJWSA, 2004). According to the Ebasco report (1988), an estimate of approximately 740 cubic yards (1,000 tons/1.35 tons per cu. yd.) were removed annually at that time.

The 342 cubic yards of sediment at the Prallsville Lock (Wickecheoke Creek outlet) from sheet and rill cropland erosion approximately equals the sediment removed annually at this location. (This does not necessarily mean that entire amount of sediment removed annually is coming from agricultural sources as there are many other sources as defined in this report.) The remainder of the sediment delivered to the outlets of the watersheds travels downstream in the D&R Canal. Travel time from Raven Rock to the Route 18 Spillway (entire Canal length of approximately 63 miles) is approximately 8 days with the velocity in the reach from Raven Rock to Lower Ferry Road estimated to be 0.9 ft/s. while the velocity decreases to an average of 0.45 to .22 ft/s. from Lower Ferry Road to the Route 18 Spillway (Gibs, et al, 2001).

The remainder of the sediment coming from the Wickecheoke Creek watershed may be either going over the weir into the Delaware River during high flow events or going further down the Canal as finer sediment as a portion of the approximately 700,000 cubic yards of sediment removed in 1985 from the 32 miles of the Canal between the Prallsville (Wickecheoke Creek) Lock and the Kingston Lock. Estimated life span of this dredging is approximately 40 years with another dredging scheduled in 2020.

The above results indicate that agricultural land uses, from a soil resource management perspective, are within generally acceptable limits for well managed land. The major exception seems to be the Upper Lockatong Creek subwatershed where a number of fields were identified as being over the T value (Table 8) and where all the vegetable fields in the entire Watershed were identified as being located (Table 7). Observations by the water purveyors, mentioned previously, that the sediment problem and their treatment costs have increased since 1997 do not conform with the cropland erosion analysis which shows the decreasing trends in the acreage of tilled agricultural land. It is interesting to note that there are no Lockatong and Wickecheoke Creek sites on Sublists 3 or 5 of the 2004 NJDEP Integrated List that show Total Suspended Solids as a parameter.

Contributions from other non-agricultural land uses are likely to be more significant. These non-agricultural contributors to sediment are explored later in this report.

Other Agricultural Sources of Sediment

During the past 60+ years a number of agricultural producers have installed surface water control practices to reduce ephemeral and gully erosion on their cropland. These practices include grassed and stoned-center waterways, diversions (divert incoming surface water runoff before it enters the cropfield) and terraces (control surface water runoff within a cropfield). These practices most often outlet directly on the surface at the edge of a cropfield or, in some cases, outlet through an underground outlet system. The surface outlets for these runoff control structures discharge into an area that is often wooded or in some other non-cropland use that would have been cleared for cropping many years ago but was too steep for cultivation. The common practice has been to install a “level lip spreader” where the outlet is equal in elevation so that the concentrated flow of water is spread out in a less erosive, sheet flow. Unfortunately, over time, leaves, branches and other debris cause the former sheet flow to become concentrated and erosive. This potential for soil erosion is further exacerbated by the presence of steep slopes between the end of the practice and the nearest stream. In some cases, the result of this process has been the development of severe, gully erosion. Figure 3 shows an example of this problem in the watershed.

A geographic analysis was performed to identify the potential for soil erosion and sediment transport from existing runoff control practices (waterways, terraces and diversions) relative to steep slopes and distances from the nearest receiving stream. Geographic layers which were intersected were a cropland layer, with field identification for those areas known to have these runoff control features; steep slopes (either greater than 8 percent or greater than 10 percent) and the distance between the field edge and the receiving waterway, in increments of 50 feet, from 50 to 250 feet.

Figure 4 shows the acres of cropland with surface runoff control practices by subwatershed. While these eroding outlet conditions may have been significant sediment sources at one time, this is no longer the case, especially when considered relative to other sediment sources.

An analysis of the land that is permanently preserved farmland in the watershed was performed as it relates to these practices. Permanently preserved farmland, as a condition of its preservation by the State, is required to have a soil and water conservation plan. Implementation of the plan is not required. Figure 5 shows the location and extent of the permanently preserved farmland in the watershed.

Figure 3 - Cropland Runoff Practice Outlet Potential Erosion

Gully formed at outlet of Terrace System along lower Wickecheoke Creek

Figure 4 – Acres of Cropland with Surface Water Control Practices by Subwatershed Within 300 Feet of Stream

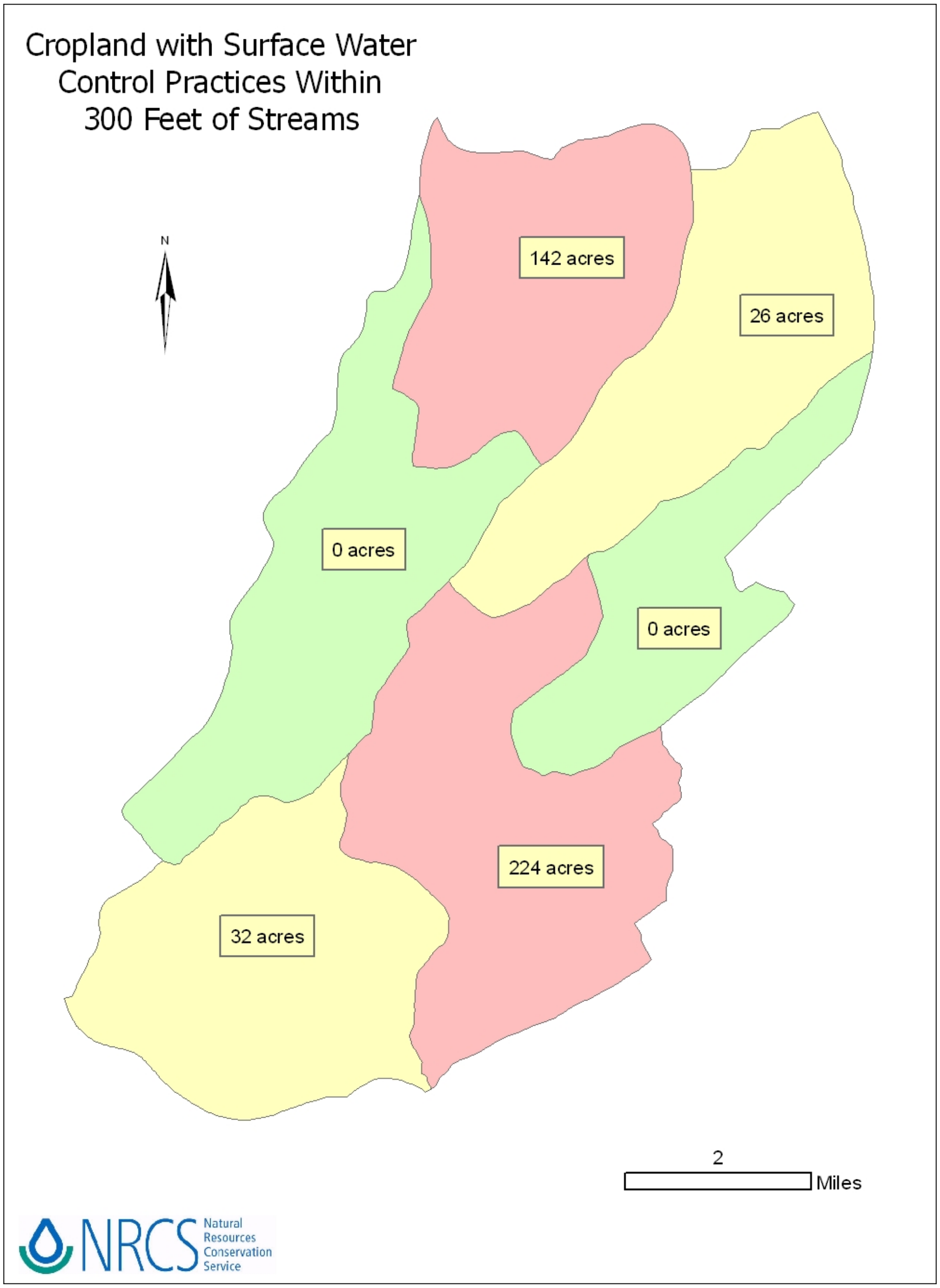
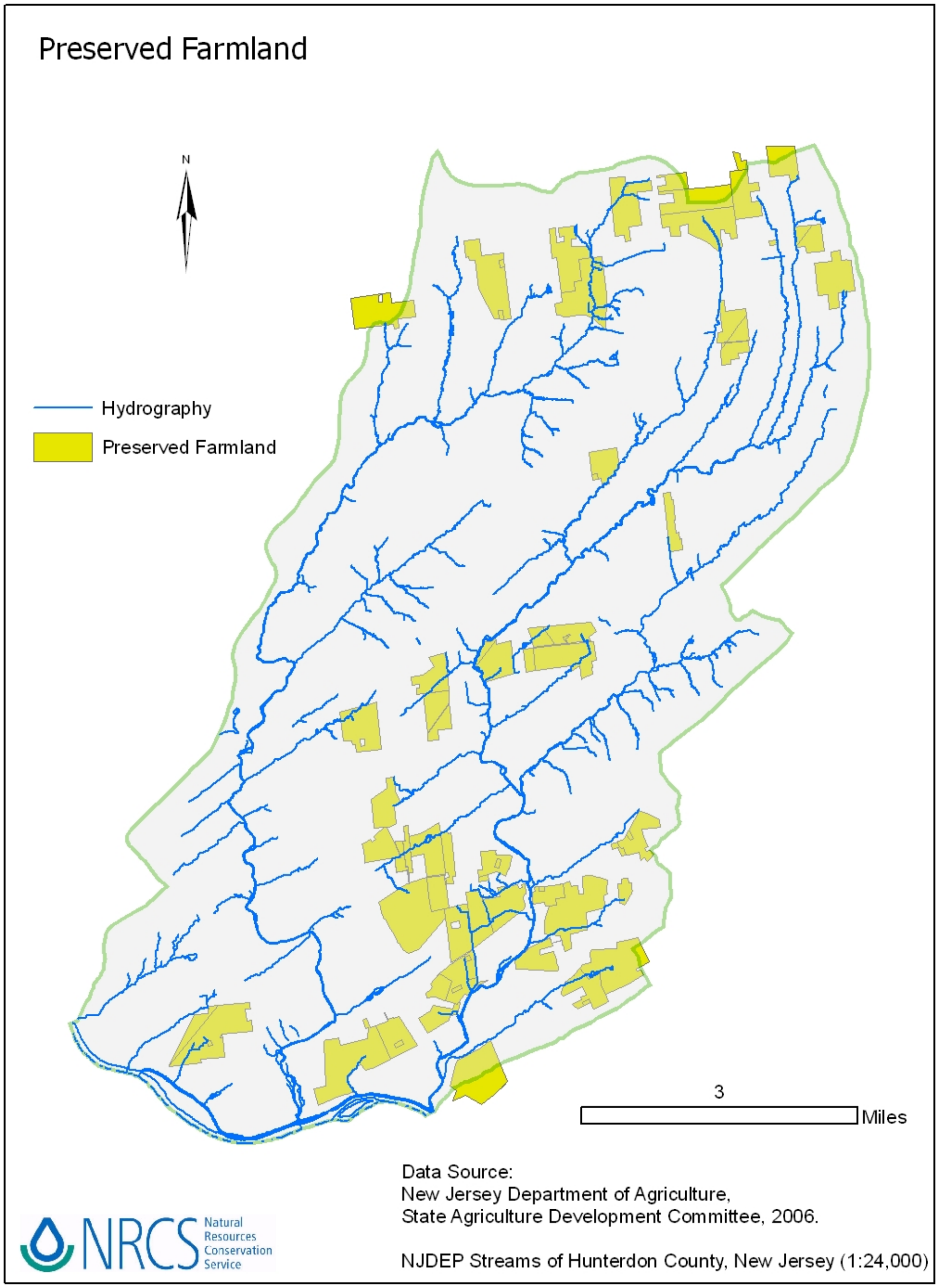


Figure 5 - Location and Extent of Permanently Preserved Farmland



Forest Sediment Sources

The "Forest" land use category accounts for about 31% of the area of the Lockatong and Wickecheoke watersheds (see Table 2.) These forests are mostly smaller woodlots but a few larger forested patches are present in some large forested wetlands throughout the watersheds and on very steep slopes in the southern reaches of the watersheds.

The NJ State Forest Service requires that forest landowners, with more than 50% of their acreage in non-appurtenant woodlands, have a forest management plan on file with the state to be eligible for farmland assessment tax evaluation. Management plans are prepared by private consultant foresters and are reviewed and approved by NJ State Forest Service foresters. State foresters visit the woodlots at least once every three years for an inspection. Many larger farms, with less than 50% of their land in forests, do not have forest management plans.

Commercial woodland harvests are very limited in this watershed (Shuart, 2006). Forestry activity in the watershed is normally limited to timber stand improvement, some pre-commercial thinning and small scale timber harvests. Timber harvest activities are also severely limited in wetlands by the NJ Freshwater Wetlands Act and along streams by the Flood Hazard Area Control Act ("Stream Encroachment"). Shuart reports that he knows of no erosion problems in woodlands in the watershed and feels that the limited forest activity should not cause excess sediment sources from woodlands. The NJ State Forest Service does not maintain data on timber harvests. They do maintain a brief database that lists the number of forestry plans and acres under a management plan by township and county.

According to Patric (1976), erosion from undisturbed as well as carefully managed forest land is 0.05 to 0.10 ton/acre/year. Using a rate of 0.1 ton per acre per year for the 10,763 acres of forestland in the watershed results in 1,076 tons of soil erosion from forestland in the watershed. A sediment delivery ratio of 33 percent yields 355 tons of sediment to the D&R Canal.

Figure 6 - Streambank Erosion on Wickecheoke Creek on Lower Creek Road

Stream Sediment Sources

Literature Review

Stream bank erosion has been identified as a significant source of nutrient and sediment loading to streams in the Chesapeake Bay Watershed and Piedmont region of Pennsylvania and Maryland (LandStudies, 2005). In addition, "legacy sediments" have been identified as being easily erodible and containing high concentrations of nitrogen and phosphorus. Legacy sediments refer to sediments that were deposited in floodplains as a result of settlement activities from early colonization to the mid-twentieth century (Legacy Sediments: A Brief History, www.landstudies.com, 2005). Stream bank erosion, based on a number of Pennsylvania Department of

Environmental Protection – funded studies has been determined to a major source of pollution, sometimes *the* major pollution source.

Methodology

Several methods of stream bank erosion estimation have been developed. Rosgen (Rosgen, 2001) developed a prediction model which incorporates a stream erodibility index and calculated near-bank stresses. Streambank characteristics involving measurements of bank heights, angles, materials, presence of layers, rooting depth, rooting density and percent of bank protection are used to develop the streambank erodibility index.

Jennings, et al. (2001) used field measurements of bank height, bankfull height, root depth, root density, bank angle and surface protection along with bank material and stratification information to determine the Bank Erosion Hazard Index (BEHI) each time a stream reach was surveyed. Generally, the higher the BEHI score the greater the streambank erosion rate.

The method used in this study has been used over the past 31 years of physically observing the behavior of streams and discussing it with fellow SCS/NRCS geologists. It is highly empirical and is a paradigm to determine volume (Olynyk, 2006). A stream's bank must first be determined to be eroding. This determination is a straightforward conclusion based on the bare surface of the bank itself. If there is evidence of vegetative growth, then the bank is assumed to be non-eroding. If bare soil is visible, the bank is assumed to be eroding. Rock lined streambanks are almost always non-vegetative but their susceptibility to erosion is quite low and requires large, episodic, and sometimes catastrophic hydrologic events.

Once a streambank is determined to be eroding, the volume of material eroded is calculated. First the length of the eroded segment is determined, followed by the height of the eroding portion of the bank. The height is usually measured from the streambed up. Note that occasionally, when a stream is experiencing abnormally high flows, this distance must be either estimated or measured when the streamflow ebbs.

Also note that the height is the height of the entire streambank, since undercutting would eventually cause the entire slope to fail. Additionally, if there is evidence of vegetative growth near the streambed but then obvious erosion above it, the cause of erosion is almost never the stream. Rather, the bare streambank above the vegetative height is being attacked from the surface or, on very rare occasions, seeps within the bank.

The third measurement necessary to complete a volumetric calculation is the surficial distance perpendicular from the stream. This is commonly referred to as the lateral recession. Most of this agency's erosion calculations are based on annual assessments. Therefore, a lateral recession rate would be a distance per year. This distance, when obtained by observers inexperienced at determining lateral recession rates, is almost always overly aggressive, i.e., the number is way too high. It is suggested that the observer estimate the lateral recession over ten years. This appears to temper the penchant for inexperienced, overly high estimates. The ten year recession is then simply divided by ten to establish an annual recession rate.

The three distances, length, height, and lateral recession of an eroding streambank now are used to determine the volume of material annually eroded from the particular segment in question. There are instances where weight (often in tons) is the desired calculation. Highly arenaceous soils may have a bulk density of as little as 80 pounds per cubic foot, while argillaceous soils may reach 120 pounds per cubic foot. An average bulk density of 100 pounds per cubic foot is therefore a convenient value often used to convert volume to pounds per cubic foot, and from there a straightforward calculation to the popular tons and tons per year (Olynyk, 2006).

Results

Table 10 shows the results of a stream survey of streambank erosion that was made in August 2006. The survey was made from field observation at a limited number of access points along the streams. This estimate was based on a GIS-generated total stream length for each of the six subwatersheds. This calculation was based on an assumption that between one and two percent of the streambank was eroding. The total estimate for streambank erosion is 248 tons per year of sediment.

Table 10 also shows a second estimate that was made using the main stem and tributaries for each of the six subwatersheds. This calculation assumed that the entire one side of the main stem was eroding. The total estimate for streambank erosion is 12,295 tons per year of sediment.

Discussion

Field observations indicate that streambank erosion is a contributing source of sediment to the Canal. Streambank erosion does occur throughout the watersheds. Streambank erosion not only serves as a source of sediment but is also a significant threat to the integrity of several county and municipal roads.

One hypothesis could be that episodic events such as Hurricane Floyd and other intense precipitation events may be putting large loads of sediment and rubble into the streambeds which in turn move downstream incrementally, similar to a conveyor belt, into the Canal.

Wolman and Schick (1967) discussed post-colonial land use changes in the northeastern United States and its effect on sediment yield. They proposed that in the late 1800s, when forestland was converted to agriculture, sediment yields increased from 100 tons per square mile to 600 tons per square mile. During the 1960s, many rural areas became urbanized resulting in another increase in sediment from construction activity which resulted in sediment yields exceeding 2,000 tons per square

Table 10 – Lockatong and Wickecheoke Creek Watersheds Streambank Erosion

Subwatershed*	tributary streambank total length (miles) both banks	Main stem streambank (miles) both banks	total length (ft.)	trib length (ft)	main length (ft)	Main banks as % of whole for subwatershed	1% of total stream network in ft eroding./100' on main stem only	2% of total stream network in ft. eroding/100' on main stem only	Typical Ht (ft.)	Lateral Recession(ft/yr)	cubic ft	Tons/yr	Lower Limit Estimate**	one side main stem eroding for entire length (cubic ft.)	Tons/yr	Upper Limit Estimate***
1	40.2	4.2	234432	212256	22176	9%	9.46	18.919	3	0.05	351.65	17.582		15919	795.96	
2	50.2	13.1	334224	265056	69168	21%	20.70	41.39	4	0.15	2005.3	100.27		79517	3975.8	
3	54.1	9.7	336864	285648	51216	15%	15.20	30.408	5	0.05	842.16	42.108		35706	1785.3	
													159.96			6557.1
4	56.3	11.6	358512	297264	61248	17%	17.08	34.168	3	0.05	537.77	26.888		22295	1114.7	
5	34.5	4	203280	182160	21120	10%	10.39	20.779	4	0.15	1219.7	60.984		54648	2732.4	
6	57.3	14.8	380688	302544	78144	21%	20.53	41.054	5	0.05	951.72	47.586	87.872	37818	1890.9	5738.04
TOTALS													247.83			12295.14

* Subwatershed:
1 – Upper Lockatong Creek
2 – Middle Lockatong Creek
3 – Lower Lockatong Creek
4 - Upper Wickecheoke Creek
5 - Middle Wickecheoke Creek
6 – Lower Wickecheoke Creek

** Lower Limit Estimate (Max Olynyk, August 2006)
*** Upper Limit Estimate – assumes one side of the entire length of the main stem eroding

mile. The estimated yield per square mile in the Lockatong and Wickecheoke Creek watershed is 127 tons per square mile. This would place this watershed between a watershed with predominantly forested land use and a watershed with more intensive agricultural land use in terms of sediment production.

Costa (1975) estimated that land clearing for agriculture caused 34 percent of eroded sediment to be transported through the basin and 66 percent was retained in storage. Of the 66 percent of sediment in storage, 21 percent was deposited on floodplains and 79 percent was retained on hillslopes as colluvium and sheetwash deposits. Costa found that channels initially responded to the increased sediment load by aggrading. As sediment loads decreased as a result of decreasing agricultural practices and the use of soil conservation practices, stream channels began to incise and scour of stream channels became an important source of sediment. The highest rates of erosion were observed on Piedmont streams due the two centuries of farming that disturbed the topsoil.

Recent studies in Pennsylvania show that 50 to 90 percent of the sediment load generated in a watershed is not coming from overland flow as previously thought, but from the stream channel banks themselves (POWR, 2005). In two watersheds, the Baltimore County Little Gunpowder Falls Water Quality Management Plan using the Storm Water Management Module (SWMM) pollutant load model provided an estimate of the amount of sediment attributable to washoff from the watershed and the amount attributable to stream channel erosion. For the Chesapeake Bay watershed as a whole approximately two-thirds of the sediment load was the result of channel erosion and not watershed sediment contribution (Langland and Cronin, 2003).   This is consistent with the findings of Trimble (1997), where stream channel measurements from 1983 to1993 in San Diego Creek indicated that two-thirds of the sediment yield was the result of channel erosion.

Recently, technology to differentiate the source of fine sediments in the suspended load of streams using naturally occurring radionuclides has been applied within the Goodwin Creek watershed in north central Mississippi as part of the Conservation Effects Assessment Program (CEAP).   This watershed is one of twelve benchmark CEAP watersheds across the country which have been chosen to evaluate the effectiveness of conservation practices applied under various landscape and agricultural conditions in difference parts of the country. Preliminary data from Goodwin Creek show that fine sediment is predominantly derived from the land surface during the initial part of a runoff event. The latter parts of the same runoff event indicate that the sources of fine sediment shifted to predominantly channel bank sources (Wilson and Kuhnle, 2006).

Figure 7 - Streambank Erosion on Plum Brook Upstream of Locktown-Flemington Road

Figure 8 - Streambank Erosion on Wickecheoke Creek at Worman Road

Road Surface and Stormwater Management Sediment Sources

Earlier in this report there was a discussion of the impact of the road network of a watershed on the effective drainage density, that is, the combined density of the stream network and the road network. Roads increase the efficiency of the water removal from a watershed by decreasing the time it takes for water to move to a receiving stream or water body. This often results in increases in the volume and rate of runoff as well as the sediment delivery to the outlets of the watersheds. Digital information on the location and extent of roads (both public and private), bridges and culverts in the watershed was obtained from Hunterdon County. Based on this information, Table 11 shows the natural drainage density and the effective drainage density by subwatershed. The Hunterdon County GIS data shows that there are 35 stream crossings and 209 culverts in the watersheds. Table 12 shows the number of acres of roadways in each subwatershed. An average road width of thirty (30) feet was used to determine the surface area (includes cut and fill slopes) of the roadway exposed to rainfall impact. Based on this information, the average percent impervious surface in the watershed due to road surfaces is one percent (Table 12).

Table 11 – Stream Drainage Density and Effective Drainage Density Adjusted for Road Network Connectivity to Streams in Lockatong and Wickecheoke Creek Watersheds

Watershed/Subwatershed	Stream Drainage Density (miles/sq. mi.)	Effective Drainage Density* (miles/sq. mi.)	Increase in Drainage Density (%)
Upper Lockatong Creek	2.877	5.120	178.0
Middle Lockatong Creek	3.910	6.583	168.4
Lower Lockatong Creek	5.121	7.465	145.8
Upper Wickecheoke Creek	4.179	6.642	158.9
Middle Wickecheoke Creek	3.721	6.550	176.0
Lower Wickecheoke Creek	3.772	6.606	175.1
TOTAL	3.960	6.520	164.6

Source: Hunterdon County GIS Roads Data
Hydrography - NJDEP

* Effective drainage density refers to the combination of the stream drainage density and the man-made drainage density (due to the road network)

An analysis, using GIS technology, of the stream drainage density vs. the effective drainage density (includes the road network) shows that the drainage density of the watersheds and their subwatersheds is increased significantly by the road network.

Table 12 – Road Acres and Road Percent Imperviousness in the Lockatong and Wickechoeoke Creek Watersheds

HUC14	Subwatershed	Road Acres	Road Percent Imperviousness in Subwatershed
02040105200040	Upper Wickecheoke Creek	57	0.9%
02040105200010	Upper Lockatong Creek	46	0.8%
02040105200020	Middle Lockatong Creek	62	1.0%
02040105200050	Middle Wickecheoke Creek	39	1.1%
02040105200060	Lower Wickecheoke Creek	78	1.1%
02040105200030	Lower Lockatong Creek	55	0.9%

Source: HUC-14 - NJDEP
Road Network - Hunterdon County GIS Data

A GIS analysis was performed to determine the location of culvert outlets relative to slope, particularly in steep slope areas (defined as those greater than 8 and 10 percent) as well as the distance of the culvert outlets from streams. Nine culvert locations were identified as occurring on these steep slope locations (Table 13). The GIS data for road culverts is incomplete as a significant gully erosion problem occurs at a road culvert location near the Pine Hill Road crossing of Plum Brook in Delaware Township which is not identified in the road culvert data.

Field observations of both paved and unpaved roadways in these watersheds indicate that there can be a disproportionate (in terms of the land area affected) amount of sediment moving from both the road network and/or its drainage system and unprotected (from erosion) outlets. As was mentioned previously, one example which has been observed are several road culverts which carry intercepted road and upper lying land runoff under Pine Hill Road in Delaware Township and outlet it at the top of a 400 foot + long, 25%+ slope which drains directly into the Plum Brook. Visual observations show that a major gully is forming at the base of this long, steep slope and the voided soil is moving directly into the Brook.

Also, where road stream crossings occur, on both paved and unpaved roads, there is uncontrolled road runoff entering the stream without any sort of pre-treatment. Frequently there is little, if any, area for the installation of a detention basin, check dams or other structural measures due to the steep slopes and relatively narrow stream corridors. An example of road runoff carrying sediment into the stream network can be found at the Pine Hill Road crossing of Plum Brook in Delaware Township. Table 14 shows those locations, identified by GIS analysis, where road crossings of streams occur on slopes greater than 10 percent for a distance of at least 100 feet on one side of the stream crossing.

Table 13 – Road Culverts, Steep Slopes and Adjoining Streams

STREET NAME	ROUTE NUMBER	SLOPE GREATER THAN 10 PERCENT	SLOPE GREATER THAN 8 PERCENT	STREAM
FEDERAL TWIST RD			X	LOCKATONG CREEK
STOMPF TAVERN RD		X	X	DELAWARE R UNNAMED TRIB 2-3500
STOMPF TAVERN RD			X	DELAWARE R UNNAMED TRIB 2-3500
PAVILICA RD			X	WICKECHEOKE CREEK
UPPER CREEK RD			X	WICKECHEOKE CREEK
FEDERAL TWIST RD			X	DELAWARE&RARITAN CANAL 88672 UNT TO 88672 @ 1.00
LOWER CREEK RD		X	X	WICKECHEOKE CREEK
WORMAN RD		X	X	WICKECHEOKE CREEK-UNNAMED TRIB #3-20
ROSEMONT - SERGEANTSVILLE RD	604		X	WICKECHEOKE CREEK
*PINE HILL ROAD		X		PLUM CREEK

Source: * Based on visual observation
Culvert Data - Hunterdon County GIS
Hydrography – NJDEP
Digital Elevation Model – NJ Department of Environmental Protection (NJDEP), Office of Information Resources Management (OIRM), Bureau of Geographic Information and Analysis (BGIA)

Table 14 – Bridge Crossings, Steep Slopes and Streams Crossed

BRIDGE STRUCTURE NUMBER	STREET NAME	ROUTE NUMBER	STREAM
D325	LOWER CREEK RD		WICKECHEOKE CREEK
D496	UPPER CREEK RD		WICKECHEOKE CREEK 88536 UNT TO 88536 @ 5.40
D488	OLD MILL RD		WICKECHEOKE CREEK
K047	BYRAM - KINGWOOD RD	651	LOCKATONG CREEK 88696 UNT TO 88696 @ 5.10
D333	PINE HILL RD		PLUM BROOK
K087	MILLTOWN RD		LOCKATONG CREEK
D481	STRIMPLES MILL RD		LOCKATONG CREEK
D494	FEATHERBED LA		WICKECHEOKE CREEK 88536 UNT TO 88536 @ 5.40
D494a	FEATHERBED LA		WICKECHEOKE CREEK 88536 UNT TO 88536 @ 5.40
D304b	ROSEMONT - SERGEANTSVILLE RD	604	WICKECHEOKE CREEK
D304a	ROSEMONT - SERGEANTSVILLE RD	604	WICKECHEOKE CREEK

Source: Bridge Crossing Data – Hunterdon County GIS
Hydrography – NJDEP
Digital Elevation Model – NJ Department of Environmental Protection (NJDEP), Office of Information Resources Management (OIRM), Bureau of Geographic Information and Analysis (BGIA)

All county roads are paved (Copp, 2006). Information on the location and extent of unpaved vs paved roads was gathered from each of the four municipal road superintendents. Table 15 shows the breakdown of road types by subwatershed. In addition, there are 6.448 miles of roads shown as “private” in the watershed. These can be broken down into 0.538 miles bituminous, 0.453 miles dirt, and 5.457 miles paved.

Table 15 – Road Surface Type by Subwatershed

Subwatershed	Road Surface Type (Miles)				
	Paved	Bituminous	Unpaved	Dirt	Total
Upper Wickecheoke Creek	21.241	2.129	0.000	0.000	23.370
Upper Lockatong Creek	11.963	6.684	0.348	0.000	18.995
Middle Lockatong Creek	19.382	5.492	0.000	0.899	25.773
Middle Wickecheoke Creek	13.542	2.028	0.498	0.000	16.068
Lower Wickecheoke Creek	20.729	6.931	4.680	0.000	32.340
Lower Lockatong Creek	15.484	5.241	2.026	0.000	22.751
TOTALS	102.341	28.505	7.552	0.899	139.297

Source: Paved, Bituminous and Dirt – Hunterdon County Highway Department
Unpaved – Delaware, Franklin, Kingwood and Raritan Twnshp Hwy Departments

Table 16 – Road Surface Type by Municipality in Watershed

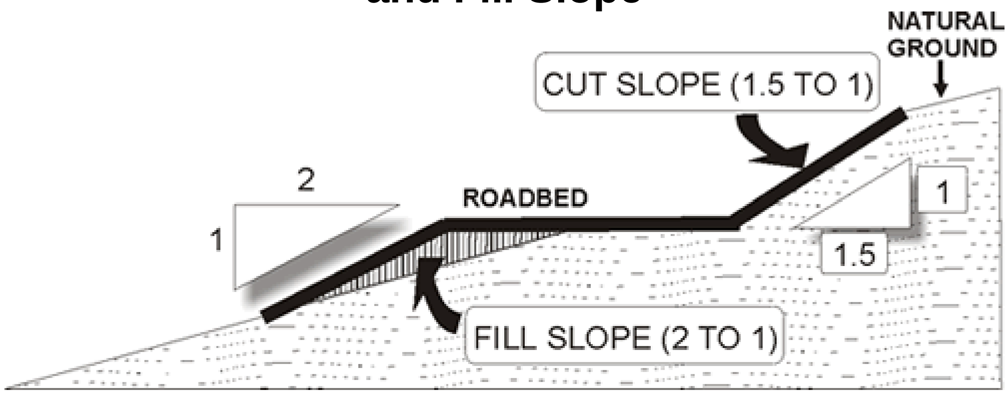
Municipality	Road Surface Type (Miles)				
	Paved	Bituminous	Dirt	Unpaved	Total*
Delaware Twp	42.587	10.238	0.000	5.478	58.303
Franklin Twp	10.334	6.898	0.000	0.341	17.573
Kingwood Twp	35.817	8.472	0.899	1.521	46.709
Raritan Twp	13.455	2.895	0.000	0.000	16.350

*Total Road miles do not include Stockton Borough which has 0.3 miles of roadway

Source: Paved, Bituminous and Dirt – Hunterdon County Highway Department
Unpaved – Delaware, Franklin, Kingwood and Raritan Township Highway Departments

Table 16 shows the road surface type by municipality in the watershed. Surface erosion occurs from nearly all roads. When ditches or culverts drain near a stream (within 200 feet), the sediment delivery ratio is 100% (Burroughs and King, 1989).

Figure 9 – Typical Roadway and its Associated Cut slope and Fill Slope



Source: Layman's Guide to Access Road Construction: Design Guidelines, North Carolina Department of Environment and Natural Resources, Division of Forest Resources

The following is the methodology used by Sturhan (1997) for determination of the soil loss from roads including their associated cutslope, ditch and fillslope (Figure 9) which has been used to analyze the road network in this watershed:

One Acre of Road (built on Moderately weathered sedimentary rocks) = 30 tons/Acre/Year

Tread: 40% of 30 Tons/Acre/Year = 12
Cutslope/Ditch: 40% of 30 Tons/Acre/Year = 12
Fillslope: 20% of 30 Tons/Acre/Year = 6

Basic Erosion Rate x Cut/Fill Slope Correction Factor For Vegetative Cover

Cutslope/Ditch: 12 Tons/Acre/Year x 0.37 = 4.44 Tons/Acre/Year
Fillslope: 6 Tons/Acre/Year x 0.18 = 1.08 Tons/Acre/Year

Basic Erosion Rate x Road Tread Surfacing Factor

12 Tons/Acre/Year x 1.0 = 12 Tons/Acre/ Year

Product of Above x Traffic/Precipitation Factor

12 Tons/Acre/Year x 2 (Mod. Traff./Active Secondary) = 24 Tons/Acre/Year

Number Acres of **Unpaved Roads** (Assumed Road Width of 30 feet including cut and fill slope x 5,280 ft/Road mile x 7.34 Unpaved Road Miles/43,560 sq.ft/A) x 29 Tons/Acre/Year = **774 Tons/Year**

One Acre of Road (built on Moderately weathered sedimentary rocks) = 30 tons/Acre/Year

Tread: 40% of 30 Tons/Acre/Year = 12

Cutslope/Ditch: 40% of 30 Tons/Acre/Year = 12
Fillslope: 20% of 30 Tons/Acre/Year = 6

Basic Erosion Rate x Cut/Fill Slope Correction Factor For Vegetative Cover

Cutslope/Ditch: 12 Tons/Acre/Year x 0.37 = 4.44 Tons/Acre/Year
Fillslope: 6 Tons/Acre/Year x 0.18 = 1.08 Tons/Acre/Year

Basic Erosion Rate x Road Tread Surfacing Factor

12 Tons/Acre/Year x 0.03 = .36 Tons/Acre/ Year

Product of Above x Traffic/Precipitation Factor

0.36 Tons/Acre/Year x 2 (Mod. Traff./Active Secondary) = 0.72 Tons/Acre/Year

Number Acres of **Paved Roads** (Assumed Road Width of 30 feet including cut and fill slope x 5,280 ft/Road mile x 130 Paved Road Miles/43,560 sq.ft/acre) x 6.24 Tons/Acre/Year = **2949 Tons/Year**

Table 17 shows the estimated amounts of sediment produced by the two road types.

Table 17 – Estimated Soil Loss by Paved vs. Unpaved Road Public Road Surfaces in Lockatong and Wickecheoke Creek Watersheds

Municipality	**Road Surface Soil Loss (Tons/Year)**	
	Paved	Unpaved
Delaware	1188	578
Franklin	389	36
Kingwood	1003	160
Raritan	369	-0-
Watershed Total	2949	774

Source: Roadway Miles - Hunterdon County GIS Data
Unpaved Roadways – Local Municipal Road Superintendents

Figure 10 shows that distribution of private and public roads as well as the location and extent of various road surfaces throughout the watershed.

The sediment contributions are due to not only road surfaces (unpaved roads) and road ditches but also to seasonally applied road sand for improving winter driving safety.
The road superintendents of the four watershed municipalities were surveyed to determine where and how much road sand they use in treating roadways within each town and the amounts were allocated according to the number of road miles maintained in each municipality within the watersheds. There are

approximately 419 tons of sand used in the watersheds per year. Hunterdon County does not use sand for winter road treatment on its roads (Copp, 2006). Table 18 shows the amount of road sand applied by municipality, based on their respective municipal total and the number of road miles within the watershed.

Table 18 – Estimated Annual Road Sand Amounts by Municipality Adjusted by Road Length within the Lockatong and Wickecheoke Creek Watersheds

Municipality	Road Sand Use in Entire Municipality/County (Cubic Yards)	Road Sand Used on Watershed Roads (Cubic Yards)
Delaware Township	60*	30*
Franklin Township	230	101
Kingwood Township	400**	288**
Raritan Township	-0-	-0-
Hunterdon County	-0-	-0-
TOTAL	690	419

Source: Hunterdon County Highway Department
Local Municipal Road Superintendents

* “Grit” – 3/8 inch stone used on unpaved roads only

** Groundup iron slag from Allentown, PA

Figure 10 - Location and Extent of Road Surface Types for Identified Private and Public Roads

Figure 11 - Streambank Erosion on Lockatong Creek at Downstream of Thatcher Road

Construction Sediment Source

A review of information obtained from the State Erosion and Sediment Control Program administered by Hunterdon County Soil Conservation District (Testa, 2007), shows that there is not a significant area of the watershed that is in active soil disturbance due to construction activities (Table 19). This program oversees the development and implementation of soil erosion and sediment control plans for any soil disturbance activity of more than 5000 square feet. Table 20 shows the percent of the actively disturbed sites one acre or less in size represent the largest proportion of sites. There is minimal sediment delivery from construction sites of these sizes due to the relative lack of connection to the existing natural drainage network. As a result of this review, it is concluded that construction activities within this watershed do not have a significant impact on sediment production to the D&R Canal.

Table 19 – Construction Sediment Sources by Municipality

Municipality*	Acres Currently Disturbed**
Delaware	212
Franklin	378
Kingwood	286
Raritan	435
TOTAL	1311

* Municipal totals represent the entire municipality including that portion within the watershed.
** Acres Currently Disturbed represent those acres on which construction activities are currently disturbing the soil.
Source: Chris Testa. 2007. Hunterdon County Soil Conservation District

Table 20 – Construction Sediment Sources by Size of Disturbed Acres

Acres Disturbed	Number of Sites	Percent
</= 1	79	44.9
2-5	53	30.2
6-10	20	11.4
11-20	7	3.9
21-150	17	9.6
-	176	100.0

Source: Chris Testa. 2007. Hunterdon County Soil Conservation District

Sediment Sources from Outside of this Watershed

The Lockatong and Wickecheoke Creek Watershed is approximately 65 percent of the New Jersey influent drainage to the D&R Canal. However, in terms of the daily flow to the Delaware and Raritan Canal, the Delaware River contributes the major part of the flow to the Canal. Localized storm events are more likely to increase the potential for sedimentation from New Jersey tributaries to the D&R Canal. Regional storm events are more likely to increase the potential for sedimentation from the Delaware River Basin to the D&R Canal. Identification of the sources of sediment to the D&R Canal from the Delaware River was not a part of this study, however, these sources may be significant based on the portion of D&R Canal flow derived from the Delaware River source (See Table 21). According to the New Jersey Water Supply Authority (Kratzer, 2007), most River sediments are removed upstream of the Bulls Island Lock, unless the Canal dike is overtopped and inundated with greater River flows.

Table 21 – Relative Streamflow of the Lockatong and Wickecheoke Creeks to D&R Canal Flow on April 26, 2007

Stream	Stream Flow
Delaware & Raritan Canal at Port Mercer, NJ	161
Lockatong Creek	23
Wickecheoke Creek	25

Source: USGS New Jersey Water Science Center, West Trenton, NJ

Summary

Table 22 – Lockatong and Wickecheoke Creek Watershed Sediment Sources and Relative Amounts Delivered to D&R Canal*

Sediment Source	**Estimated Sediment Delivered to D&R Canal (Tons Per Year)**
Cropland	2494
Forestland	355
Roadways	3314
Streambank	248 -12,300

* Does not include the Delaware River Basin sources

According to Patric (1976), the geologic norm for erosion is between 0.18 and 0.30 tons per acre per year which would amount to approximately 10,450 tons of erosion per year or 3,134 tons (33 percent sediment delivery ratio) of sediment yield to the D&R Canal from the Lockatong and Wickecheoke Creek watershed.

As was mentioned in the Literature Review, the documented amount of sediment in the Stony Brook Basin ranged from 25 to 400 tons per square mile. Based on an estimated sediment yield shown in Table 22, this 54.3 square mile watershed has a sediment yield of approximately 118 to 340 tons per square mile which falls into this range.

The estimates made for sediment sources in this watershed were based on modeling. The modeling was done both for the soil erosion process as well as to develop the sediment yield. The relative contribution of sediment from the various sources is highly dependent on the inputs to each of these models. Table 22 shows examples of sediment delivery ratios for various sediment sources.

Table 23 – Sediment Source and the Delivery Ratio

Sediment Source	**Delivery Ratio** (Percentage)
Sheet erosion	33
Gullies	80
Roadbanks	80
Streambanks	100

Source: USDA NRCS, 1983

Table 24 – Relative Soil Erosion Rates and Delivery Ratio for Sediment Sources in Lockatong and Wickecheoke Creek Watershed

Sediment Source	**Relative Soil Erosion Rate**	**Sediment Delivery Ratio (Percent)**
Agricultural Cropland	Low	33
Forestland	Low	33
Roadways	High	80
Streambank	High	100

The annual sediment yield is the product of the annual gross erosion (tons/unit area) and the sediment delivery ratio (less than 1). Many factors influence the sediment delivery ratio and, because these are not uniform from watershed to watershed, the relationship between sediment yield and erosion varies considerably. Factors influencing the sediment delivery ratio include the sediment source, proximity of sediment sources, transport system, texture of eroded material, depositional area, and watershed characteristics. Table 24 shows the sediment sources and their relative soil erosion rate and their sediment delivery ratio.

Agricultural Phosphorus Sources

Sources of contamination of freshwater by phosphorus can come from a number of agricultural sources including inorganic fertilizers, animal manures and others. Wildlife wastes have been identified as a contributing factor to excessive nutrients and pathogens causing water quality problems in some areas of the country.

Animal Waste

Animal waste, when it is improperly managed, can be a source of phosphorus to surface water in a watershed. The potential for agricultural animal waste is shown by reviewing the trends in animal numbers from Farmland Assessment data for the four municipalities (Delaware, Franklin, Kingwood and Raritan Townships) in the watershed over the past twenty years (Table 19). In nearly all categories there has been a downward trend in terms of number of animals.

The local Natural Resources Conservation Service office indicates that there are no Environmental Quality Incentives Program (EQIP) contracts/plans and that there are no comprehensive nutrient management plans (CNMP) in this watershed. Existing soil and water conservation plans are for two individual farm operators who each rent approximately 1000 acres of land in this watershed. Approximately 70 percent of the tillable land in this watershed is rented to farm operators (Bartok, 2005). Generally, the plans address crop rotation, minimum tillage, and nutrient and pest management. Also the plans include some hay planting.

Table 24 - Trends in Agricultural Animals in Lockatong and Wickecheoke Creek Watersheds Vicinity Municipalities (1983 - 2004)

Tax Year	Beef Cattle	Dairy	Equine	Sheep	Swine
1983	3407	2252	1252	2181	1640
1984	NA	NA	NA	NA	NA
1985	2534	1540	1360	1902	1412
1986	NA	NA	NA	NA	NA
1987	2604	1574	1619	2071	1839
1988	2595	1680	1363	2020	1344
1989	1348	1117	1150	1284	1154
1990	1480	888	1258	2092	1428
1991	1574	1064	1170	1965	1586
1992	1804	759	1285	1949	1164
1993	1640	1000	1121	1657	1356
1994	1863	820	1141	2086	799
1995	1886	698	1219	1962	1084
1996	1923	673	1209	1949	1000
1997	1714	721	1240	2042	793
1998	1501	518	1199	2106	843
1999	1436	516	1185	1988	971
2000	1249	510	1144	1802	850
2001	984	171	1373	1669	702
2002	1027	183	1644	1696	734
2003	1152	189	1532	1429	722
2004	1050	90	1411	1424	707

Source: New Jersey Farmland Assessment Data 1983 - 2004
NA – Data Not Available

Wildlife

Wildlife have been identified, mostly in anecdotal fashion, as a contributing factor to excessive nutrients and pathogens causing water quality problems in some areas of the country. Canada geese and white-tailed deer have been identified as possible contributors to excess phosphorus in the watershed.

Resident Canada goose populations have been increasing for several decades. Resident goose numbers increased dramatically from a statewide population of about 50,000 in 1990 to about 100,000 in 1998 according to the NJ Div. of Fish & Wildlife. Liberal hunting seasons and bag limits have been instituted in recent years to try to control the rapidly expanding resident goose population. The population is reported to be relatively stable at about 95,000 birds statewide since 2000. The population estimate for the Piedmont Region of New Jersey is about 30,000 – 40,000 resident Canada geese (T. Nichols, Personal Communication). Local resident geese congregate on open water bodies such as large farm ponds, lakes and reservoirs. In addition geese may feed in large numbers on waste grains in crop fields and grasses in large closely mowed open grass fields (ball fields, golf courses, corporate lawns). The University of Missouri (*The Water Line* – Univ. Missouri 1997) reports that each individual Canada goose dropping can include up to .016 grams of phosphorus, geese can produce up to 28 droppings per day with an equivalent of 163 grams of phosphorus (.36 pounds) annually. Much of this watershed is forested, urban or agricultural operations not attractive to Canada geese. Some cropland, wetlands and water bodies would provide suitable habitat for resident geese. It would be difficult to determine the Canada goose contribution of phosphorus to the watershed without additional detailed local goose population investigation.

White-tailed deer are managed by the NJ Division of Fish and Wildlife in discrete units called Deer Management Zones (DMZ's). The Lockatong and Wickecheoke watersheds are entirely with in DMZ's 10 and 11. Table 20 shows deer population estimates for those DMZ's since 2000. New Jersey deer harvest regulations represent some of the most liberal in the nation with hunters able to legally harvest almost unlimited number of deer if all seasons are hunted and multiple permits are purchased. Deer population estimates for the two DMZ's that make up this watershed indicate a downward trend in deer density. Deer also only represent one wildlife species of many in the watershed. Other mammals, birds, reptiles and amphibians are abundant throughout the watershed and may indeed contribute more phosphorus than deer. With an overall deer population estimate of about 50 deer per square mile, the 54 square mile Lockatong and Wickecheoke watershed could include about 2700 deer. With an average deer weight of 100 pounds it takes 10 deer to make one animal unit (1000 lb). The 2700 deer represent 270 animal units spread out over the entire 35,000 acre watershed and deer droppings should not represent a significant contribution to phosphorus.

Table 25 - Trends in White-tailed Deer Densities in Deer Management Zones 10 and 11 that include the Lockatong and Wickecheoke Creek Watersheds (2000 - 2005)

Year	**Deer Density (Deer/Square Mile)**			
	Zone 10	**5 Year Average**	**Zone 11**	**5 Year Average**
2005	48.1	58.6	45.2	43.3
2004	42.7	59.5	34.1	42.8
2003	65.5		40.5	
2002	69.9		48.1	
2001	66.7		48.7	
2000	52.9		42.6	

Source: C. Kandoth, Personal Communication

Cropland Runoff

A potential source of phosphorus in surface water is agricultural cropland runoff.

Phosphorus Index

The Phosphorus Index is a method to evaluate the relative risk of surface water impacts from the phosphorus contained in land applied organic wastes. The Index operates on a field specific basis. It is important to remember that the Phosphorus Index is a general assessment tool that has limitations, and should be viewed as such. This tool is intended to help in the selection of management alternatives that can reduce the probability of phosphorus impacting water resources. Any attempt to use this tool as a regulatory method is beyond its scope and purpose.

The Phosphorus Index includes two separate methodologies: one for typical crop production systems and one for systems utilizing raised beds and plastic mulch. The reason for this is the unique runoff characteristics of the latter. The Phosphorus Index for a raised bed-plastic mulch crop system is completely independent from the Phosphorus Index for typical crop production systems and stands alone.

Table 25 shows that within each methodology, a series of site characteristics critical to potential phosphorus loss are listed down the left column, with weighting factors in parentheses. Site characteristics that are critical to potential phosphorus loss include the soil erosion, soil runoff class, distance of the phosphorus application edge from surface water, soil test phosphorus values and phosphorus application method for both organic and inorganic sources. The relative risk factors for each are listed across the top with multipliers in parentheses. The score for each site characteristic is obtained by multiplying the weight factor by the risk factor.

Table 26 shows the methodology for computation of the site characteristic factor B soil runoff class.

The Phosphorus Index was applied to the same sample of the 1500 fields used in the sheet and rill erosion analysis earlier in this report. This amounted to approximately 300 fields in this 20 percent sample. The results of this analysis are shown in Table 28.

Buffer Distance Analysis for the Selected Cropfields

The Natural Resources Conservation Service initially estimated the annual soil loss on a 20 percent sample of fields of the total of approximately 1500 fields in the watersheds. A multi-ring analysis to determine the Site Characteristic C. The distance of phosphorus application from surface water was determined by using geographic information system technology. The results of this analysis for all of the approximately 1500 fields in the watershed are shown in Table 27.

Table 26 - New Jersey Phosphorus Index for Typical Crop Production Systems

Site Characteristic	None (0)	Low (3)	Medium (5)	High (10)	Very High (20)	Score
A. Soil Erosion (1.5)	<1 ton/ac/yr	1-5 tons/ac/yr	6-10 tons/ac/yr	11-15 tons/ac/yr	>15 tons/ac/yr	
B. Soil Runoff Class* (1.0)	Negligible	Very low or low	Medium	High	Very High	
C. Distance of P application edge from surface water (1.5)	>250 ft.	100-250 ft	50-99 ft	20-49 ft	<20 ft	
D. Soil Test P Rutgers values (1.5)	Very Low (Below optimum)	Low (Below optimum)	Medium (Below optimum)	High (Optimum)	Very High** (Above optimum)	
E. Phosphorus Application Method: Both organic and inorganic sources (1.0)	None applied	Placed with planter deeper than 2 inches; or injected deeper than 2 inches; or applied and incorporated less than 7 days before planting crop	Applied and incorporated 7 days – 3 months before planting crop; or surface applied to hayland during the growing season	Applied and incorporated> 3 months before planting crop; or surface applied < 3 months before planting crop; or surface applied to hayland outside of the growing season; or surface applied to good pasture (70% or more living cover)	Surface applied to overgrazed pasture with less than 30% living cover; or surface applied without incorp. >3 months before planting crop	

* See Soil Runoff Class Designation

** Where soil test lab results indicate P levels in the very high range where no additional P is recommended for crop growth purposes, P may still be applied in the organic (manure/compost) form in accordance with the recommendations of this Index without known environmental problems. However, there may be nutrient-plant-animal interaction consequences thus suggesting avoiding additional P applications in both fertilizer and manure sources.

Table 27 - Soil Runoff Class Designation: for Use in Phosphorus Index, Site Characteristic B

Slope %	EFH Ch. 2 Curve Number <50	EFH Ch. 2 Curve Number 51-60	EFH Ch. 2 Curve Number 61-70	EFH Ch. 2 Curve Number 71-80	EFH Ch. 2 Curve Number >80
<1	Negligible	Negligible	Negligible	Negligible	Very Low
1-2	Negligible	Negligible	Very Low	Very Low	Low
3-5	Negligible	Negligible	Low	Low	Medium
6-8	Very Low	Very Low	Medium	Medium	High
9-16	Very Low	Low	Medium	High	Very High
>16	Low	Medium	High	Very High	Very High

EFM Ch. 2 – NRCS Engineering Field Handbook Chapter 2

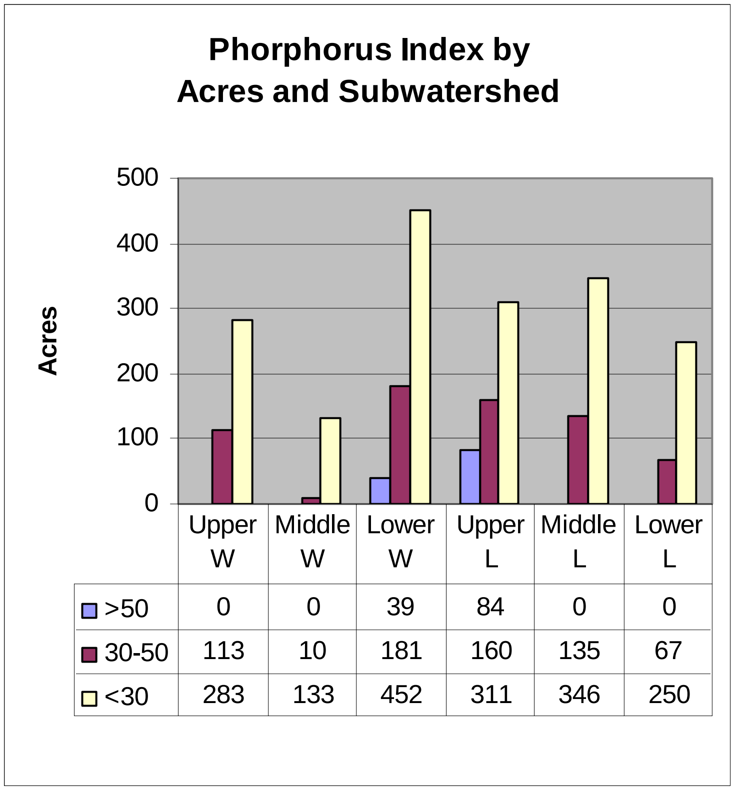
Table 28 - Phosphorus Application Distance from Surface Water

Phosphorus Application Distance (Feet)	Number of Fields	Percent of Fields
>250	847	56.5
100-250	175	11.8
50-99	104	6.7
20-49	140	9.3
<20	234	15.7
-	1500	100.0

Table 29 – Phosphorus Application Distance from Surface Water and Phosphorus Index by Field

Phosphorus Index / Phosphorus Application Distance (Feet)	Phosphorus Index <30	Phosphorus Index 30 - 50	Phosphorus Index >50
<20	1	32	11
20-49	3	58	14
50-99	25	67	14
100-250	55	74	14
>250	182	8	0

Figure 12 – Phosphorus Index by Acres and Subwatershed



Phosphorus Index Designation

<u>>100 Very High Potential for P Loss</u> – Very high potential for P movement from this site given current management practices and site characteristics. No additional phosphorus should be applied to this site. Active remediation techniques should be implemented in an effort to reduce the P loss potential from this site.

<u>51-100 - High Potential for Phosphorus Loss</u> – High potential for P movement from this site given current management practices and site characteristics. Phosphorus-based nutrient management planning should be used for this site. Phosphorus application should be limited to crop removal of P, or soil test based P recommendations. All practical management practices for reducing P losses by surface runoff, subsurface flow, or erosion should be implemented.

<u>30-50 - Medium Potential for Phosphorus Loss</u> – Medium potential for P movement from this site given current management practices and site characteristics. Nitrogen-based nutrient management planning is satisfactory for this site. However, resultant phosphorus applications should not exceed 1.5 times the P amount to be removed by the crop. Practices should be implemented to reduce P losses by surface runoff, subsurface flow, and erosion.

<30 - Low Potential for Phosphorus Loss – Low potential for P movement from this site given current management practices and site characteristics. There is a low probability of an adverse impact to surface waters from P losses from this site. Nitrogen-based nutrient management planning is satisfactory for this site. Soil P levels and P loss potential may increase in the future due to N-based nutrient management.

Table 30 - Phosphorus Index Analysis Results for Selected Cropland Sample

Phosphorus Index	Number of Fields	Percent of Fields
>100	0	0.0
51-100	9	3.0
30-50	71	23.6
<30	221	73.4
TOTAL	301	100

Table 29 shows the results for the number and percent of the sampled cropfields in terms of their phosphorus index. The range of phosphorus index values is from 12.5 to 67.5 with a mean of 24.7.

Conclusions

The Natural Resources Conservation Service staff has made multiple visits to the watersheds to view and analyze the status and trends of land use and management as it relates to the identified problem: sediment in the D&R Canal. As previously stated, this analysis did not evaluate sediment sources, which may be significant, from the Delaware River Basin, however, it is believed that most River sediments are removed upstream of the Bulls Island Lock, unless the Canal dike is overtopped and inundated with greater River flows (Kratzer, 2007).

The Revised Universal Soil Loss Equation (RUSLE) model used above, shows that sheet and rill erosion due to agricultural land use contributes a relatively low amount of sediment. In fact, soil erosion for the vast majority of agricultural cropland is well within acceptable levels for the management of the soil resource. Protection of the water resource may require additional best management practices other than those normally used for the protection of the soil resource.

Based on the scientific literature for similar watersheds in the Piedmont Plateau reviewed above, it seems highly likely that stream channel erosion and its associated sediment yield are higher than was identified here. Further it seems highly likely that legacy sediments from past (not current) agricultural practices are contributing a significant portion of sediment to the D&R Canal. Episodic events, such as Hurricane Floyd (1999) and Hurricane Ivan (2004), have moved massive amounts of sediment from the Delaware River directly into the D&R Canal. These events have also accelerated channel erosion along the main stem and tributaries in these watersheds.

Roads and their associated drainage network were evaluated using a model in use in Washington state. GIS technology identified the location and extent of the public and private road network and its impact on increasing the effective drainage of the watershed. Sediment originating from the road system and its associated drainage network is considered to be a significant sediment source as a result of its connectivity to the natural drainage network and ultimately the D&R Canal.

Agricultural Cropland and Forestland Erosion

The earlier studies done by NRCS and EBASCO suggest that cropland erosion in these watersheds was much greater than it is today. This is the result of much greater acreages of tilled crops such as corn and soybeans in these watersheds in 1987 vs. today. As a result of field observations and analysis of the current cropland sheet and rill erosion, it is concluded that sheet and rill erosion from agricultural cropland is not a major source of sediment to the Canal.

Additionally, the analysis of another land use, forestland, has determined that sheet and rill erosion from forestland does not significantly contribute to the stream sediment load. The relative contributions of these land uses could change in an upward direction if, due to market conditions, the type of tillage practices and intensity of cropping were to change on agricultural cropland or an increased amount of logging were to take place on forestland. Currently, the trends in the intensity of use for agricultural and forested lands here do not appear to be increasing the sediment source risk.

Agricultural Surface Water Practice Outlet Erosion

Field observations and aerial photo interpretation have identified a number of crop fields, particularly in the lower part of the Wickecheoke Creek watershed, that have had gradient diversion and/or terrace systems installed to control runoff on these fields. These practices are often as much as 50 years old. These practices when originally built, often with technical assistance from the Natural Resources Conservation Service, were to have “level lip spreaders” areas to convey surface runoff at a non-erosive velocity to the outlet. Unfortunately, over time, these areas have not been maintained. These practices often outlet into outlets which, over time, have become degraded due to the volume and velocity of runoff being directed to them. These outlets can be along property line hedgerows, field boundaries and other unprotected areas. As a result of the concentrated runoff being outletted into these areas significant gully erosion may be present. This gully erosion may be a significant contributor of sediment.

Over time, the technology for controlling cropland surface water runoff has changed from gradient structures to underground outlet structures which can better store and release surface water runoff from a crop field at a safer volume and velocity. Also, in many cases, the original purpose for the practice has changed. For example, corn, soybeans or other cultivated crops may no longer be grown on a field but rather the field is in permanent hay. These type of cropping or other tillage changes may eliminate the need for these practices. While these eroding outlet conditions may have been significant sediment sources at one time, this is no longer the case, especially when considered relative to other sediment sources.

Stream Corridor Erosion

In addition, another significant sediment source is stream corridor erosion resulting from streambank erosion and streambed erosion. This source has been exacerbated by recent episodic events such as Hurricane Floyd (1999) and Hurricane Ivan (2004) and other higher intensity precipitation events and the average annual precipitation in New Jersey during the 1971-2000 period to the present being nearly three inches greater than the period of record (1895-2006) (Robinson, 2007). Stream corridors also are likely to carry the vestiges of the legacy sediments from the previously high sheet and rill erosion from agricultural cropland.

Roadways and their Associated Drainage System

Water, when it is relatively free of sediment, acts as a “pollutant” in trying to dissipate its energy it will tend to pick up sediment. The road network and its associated drainage system is identified as a significant contributor to sediment to the Lockatong and Wickecheoke Creeks and ultimately to the Delaware and Raritan Canal. The road network, as it is discussed here, includes both public and private roads. There are several reasons for the road network and its associated drainage system to be so identified and they include the increase in the volume and rate of runoff, as well as the greater efficiency of sediment delivery to the outlets of the watersheds, on this land use. This is particularly true where road runoff is channeled through large culverts that outlet onto unprotected slopes directly into streams as well as at a number of road way stream crossings. The current trends in this land use are to increase water removal efficiency (paving of formerly unpaved roads) and to increase in the number of acres in this land use predominantly through the widening of existing public roads and the development of private roads.

Construction Erosion

A review of information obtained from the State Erosion and Sediment Control Program administered by Hunterdon County Soil Conservation District (Testa, 2007), shows that there is not a significant area of the watershed that is in active soil disturbance due to construction activities. The percent of the actively disturbed sites one acre or less in size represent the largest proportion of sites. There is minimal sediment delivery from construction sites of these sizes due to the relative lack of connection to the existing natural drainage network. It is concluded that construction activities within this watershed do not have a significant impact on sediment production to the D&R Canal.

Recommendations

(See Executive Summary for Prioritized Recommendations)

Institutional and Further Study

- Develop and implement an on-going information, technical assistance and cost sharing program for all property owners in the watersheds to implement best management practices.

- Install signage as the public enters the watersheds indicating that the watersheds are a water supply area. Studies have shown that watershed signage incrases awareness in terms of identification of local watersheds as well as behaviors and actions that impact local water quality (Ellwood, 2003).

- Acquire conservation easements from property owners and require implementation of a forest management plans that have a primary objective of clean and abundant water.

- This study has been heavily dependent on modeling to develop estimates of the sources of sediment to the D&R Canal. It is recommended that a "fingerprinting" study using radioisotopes be made to more accurately determine the sources of sediment.

Cropland

- Require the development and implementation of a soil and water conservation plan for resource management systems for all farmland assessed property in the watershed.

- Require a conservation lease on all rented agricultural land that is at least five years in length and renewable at least a year in advance of termination and provide compensation on a pro-rated basis including conservation practices and soil amendments.

- Retrofit existing gradient diversion and terrace systems where these are causing severe gully erosion at their outlets particularly where cropping and tillage practices obviate their need. Stabilize eroded former surface water runoff outlets. Any new diversion or terrace systems must try to maximize storage and outlets should be to stable outlets where they will not result in new erosion.

- Install underground outlet gradient diversion and terrace systems, where existing cropping and tillage practices require surface water runoff control.

- Improve water infiltration into the soil on existing hay land by various measures including avoiding agricultural field operations that increase soil compaction, increasing soil organic matter, and others.

- Install permanent buffer strips on the approximately 32 percent of the cropland with a distance of 100 feet or less between the cropland and stream corridors using such programs as the Conservation Reserve Enhancement Program (CREP).

- Install conservation systems on the approximately 7 percent of the fields that are identified as having soil losses over the T value.

Forestland

- Require the development and implementation of a forest management plan for farmland assessment that includes practices for water quality and quantity as well as species richness and diversity of tree age and size class in addition to forest stand improvement. Measures may include:

    - Micro-topography restoration for surface water storage
    - Better deer management to protect understory and groundcover for reduced phosphorus and nitrogen runoff

- Identify and preserve old-growth forest as an important record and benchmark for soil and vegetation changes over time.

Stream Corridor and Floodplains

- Modify stream corridor to reduce the “conveyor belt” movement of sediment, cobbles and other rubble downstream toward the D&R Canal. The “conveyor belt” refers to the fact that material moves downstream incrementally and is highly dependent on the volume of streamflow. Measures may include:

    - Instream placement of measures to slow down and impede the above Movement
- Implement the most environmentally friendly streambank stabilization techniques possible to protect eroding streambanks near roads, bridges and homes. This may include soil bioengineering systems utilizing native plant materials and low volumes of rock with practices such as stone toe protection and rock stream barbs.
- Plant willows and grasses, where there is sufficient sunlight, to provide closer cover of soil that can lay down during flood events

Roadways and Associated Drainage System

- Install measures to reduce the volume and velocity of surface water runoff to stream corridors from roadways. Measures should include the relocation of outlets and manner of conveyance of road surface water runoff that is currently disposed of through road culverts over steep slopes into streams or steep road gradients near road stream crossings. Measures may include:

  - Conveyance measures including stone-center waterways and underground outlets

  - Outlets to include protected outlets or sediment basins.

Pasture Land and Exercise Lots

- Exclude all livestock from stream corridors leaving a buffer area to intercept any animal waste runoff toward the stream.

- Separate exercise lots from pasture land.

- Practice rotational grazing and provide livestock adequate water so as to enhance water infiltration in soil and vegetation quality for livestock needs.

- Implement pasture management practices to minimize accumulation and runoff of animal waste.

- Improve water infiltration into the soil on existing pasture land by various measures including avoiding agricultural field operations that increase soil compaction when conditions are wet, increasing soil organic matter, and others.

- Exclude all clean water from stockpiled animal waste and dispose of animal waste by recycling in the soil on cultivated land.

Rural Residential Land

- Minimize footprint and disturbed area of house and preserve all other topography and vegetation of the site.

- Minimize driveway length and nature of treatment (unpaved better than paved).

- Practice regular septic system maintenance with pumping done at a minimum of once every three years.

- Install raised beds on the contour and provide depressional rain garden to slow runoff.

Natural Resources Conservation Service Personnel

Name	Title	Years of Service
Gail Bartok	District Conservationist	20
Gary Casabona	GIS Specialist	10
Tim Dunne	Biologist	26
Kent Hardmeyer	Resource Conservationist	38
Fred Kelly	Resource Conservationist	26
David Lamm	State Conservation Engineer	28
Max Olynyk	Geologist	30
ShayMaria Silvestri	GIS Specialist	10
Ron Taylor	State Soil Scientist	37
Chris Smith	State Resource Conservationist	27
Gregory Westfall	Water Resource Planner	34

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